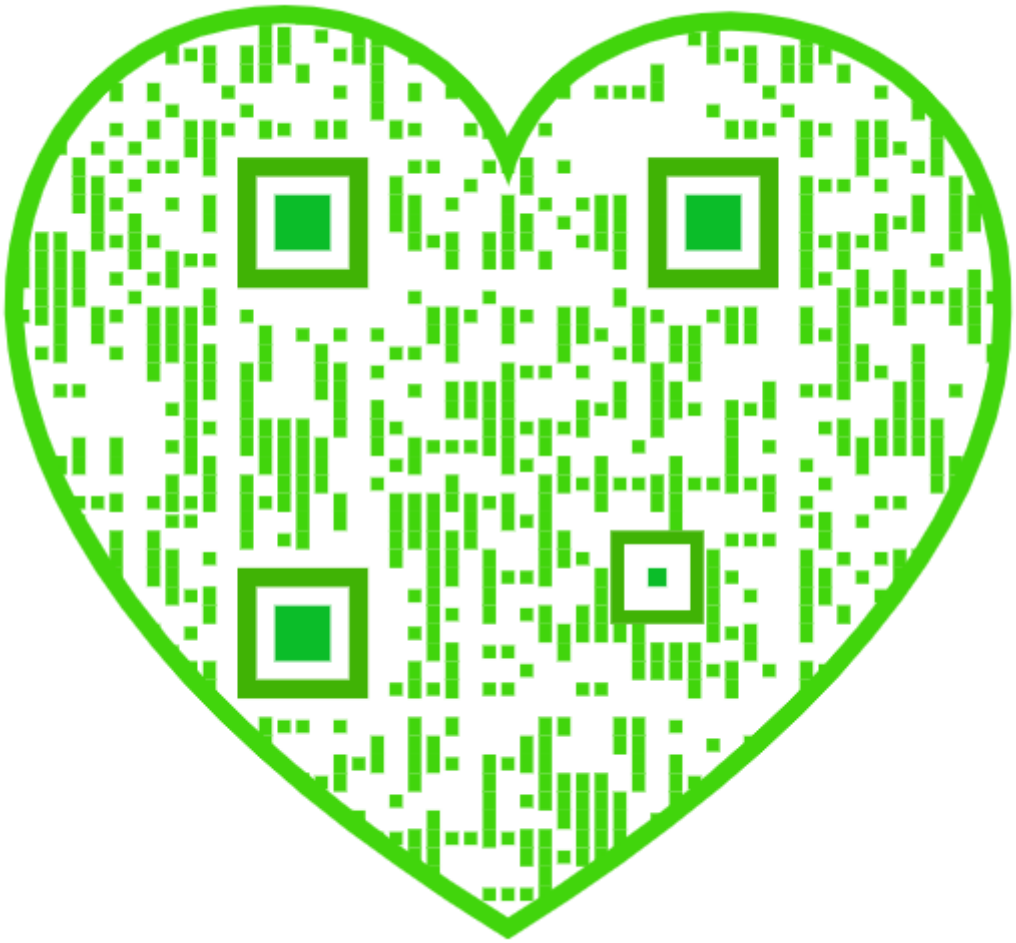

WELDING

A PRACTICAL TREATISE ON THE APPLICATIONS OF ELECTRIC, GAS, AND THERMIT WELDING TO MANUFACTURING AND REPAIR WORK

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INTRODUCTION

WHEN any industry or art stands practically still for a few thousand years and then suddenly begins developing at an enormous rate, it is always sure to attract attention and receive a large amount of study. This results in still more rapid development.

¶ The art of welding had been limited almost entirely to joining a few of the metals by hammering them together, either hot or cold, from the beginning of history until within the present generation. Then the idea of rising high temperatures for fusing metals together presented itself and the art began to progress.

¶ Combinations of gases, electric arcs, and the heat of resistance have all been used as the means for heating the metals at the point to be welded, and practically every known metal and alloy has been successfully welded. During the Great War development was accelerated and operations performed that had been considered commercially impractical before.

¶ The development of gas welding for all sorts of repair and production work caused the arc-welding systems to improve, and this in turn made development of gas-welding systems necessary in self-defense. The result has been a greater advance in the past five years than had been made in the previous twenty-five years. Each system has its limitations, but both are good.

¶ The application of all welding processes to railroad equipment, ship building, sheet metal work, and on castings of all kinds has revolutionized many lines of manufacture, and the development of automatic machines for welding the seams of tubing, tanks, and other sheet metal articles is worthy of special note.

¶ Considerations of safety and reliability lead to careful tests, and the study of processes and the effect of various combinations of metals and their action at high temperatures has almost entirely eliminated the element of chance from modern welding operations — even the personal equation of the operator has been reduced.

¶ In this volume will be found a complete exposition of the practical side of welding by all processes, with descriptions of the more important apparatus, and no engineer or mechanic can lay claim to being up to date in his business unless he has a fair working knowledge of this subject. The demand for men with such knowledge is steady and the work is both interesting and profitable.

¶ It is recommended that the student supplement his study of this book by visits to shops having welding apparatus of the various kinds described, thus seeing for himself just how effective the processes are.

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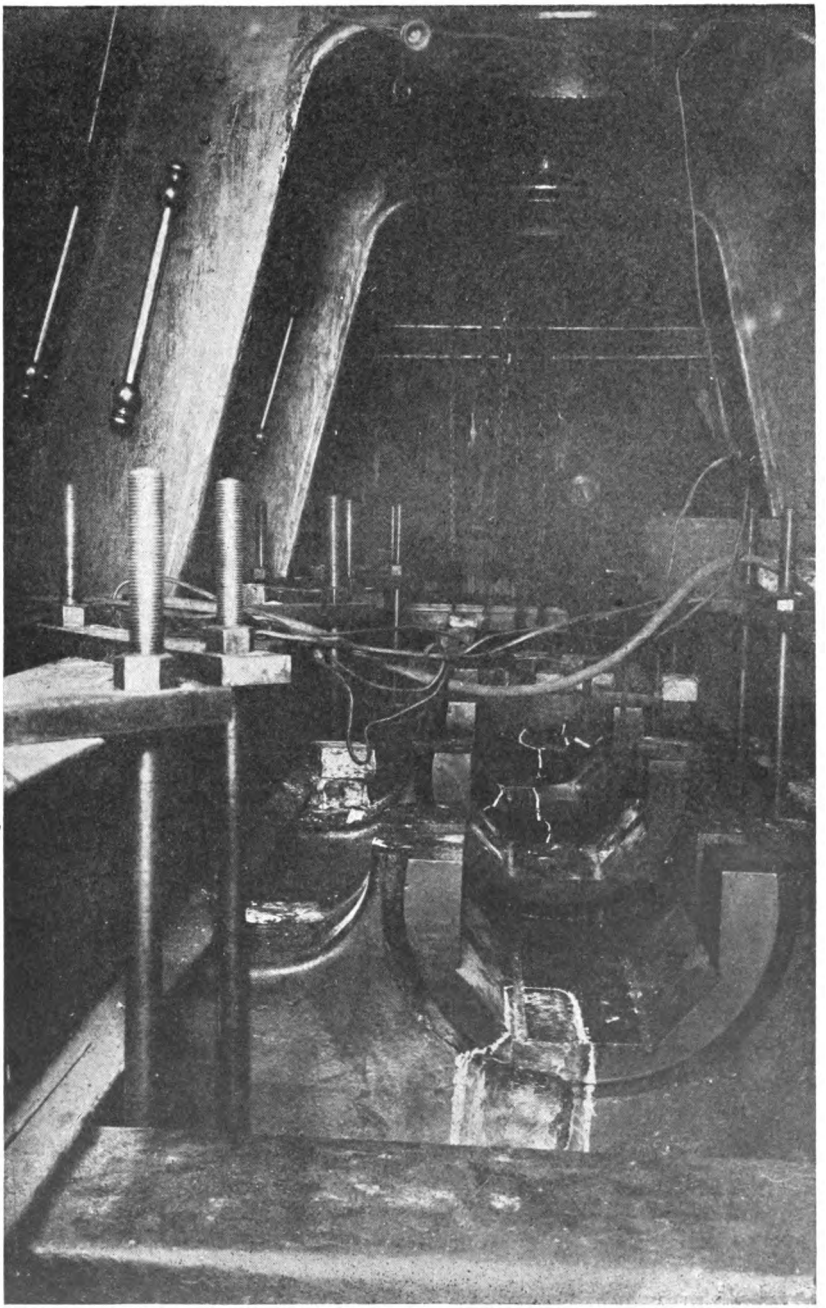


ELECTRIC WELD MADE ON A 100-TON ICE MACHINE
Courtesy Electric Welding Company, New York

WELDING

PART I

INTRODUCTION

Welding, an Ancient Art. The art of joining metals is one of the oldest known to man. Even since the first cave dweller or half-monkey man hammered his first piece of iron or copper between two stones, the development of the art has gone forward, and will probably continue to go forward as long as men use metals. The welding of iron is apparently as old as the production of that metal by man, for there is, in a temple yard of the ancient city of Delhi, India, an iron pillar nearly two thousand years old, which shows unmistakable evidences of having been welded. The shaft projects 22 feet above the surface of the ground, extends over 40 feet into the earth, and is about 16 inches in diameter. It was apparently welded into one piece from blooms weighing about 70 pounds each; the joints are as nearly perfect as if they had been made with our most modern equipment, and yet they must have been forged by hand.

Conditions for Successful Welding. Strictly speaking, "welding" is the uniting, or joining, of two pieces of metal by hammering them together while they are hot enough to be plastic, and the application of the term is thereby almost limited to work done in a blacksmith shop. Broadly speaking, however, any process by which two pieces of metal are joined by causing cohesion of the molecules of the pieces is called "welding." The best modern methods of welding are those in which cohesion is effected by means of high temperatures produced with gas or electricity. Many metals which cannot be welded by hammering may be welded by the new processes, which include brazing and soldering.

Metals are most easily welded when in that degree of plasticity between the molten and the solid states; hence, those metals which remain plastic the longest while cooling are the easiest to weld. Originally welding was almost limited to iron, platinum,

nickel, and gold, but the recent development of high temperature systems has extended the field greatly. In fact, it is safe to say that every metal may be welded by some one or other of the modern methods. So recently as 1910 it was considered impossible to weld aluminum. Today not only aluminum but practically every kind of alloy is successfully welded by both electric and gas systems.

Successful welding by any method depends almost entirely upon three factors: *flow, cohesion,* and *temperature.* The metal must tend to flow under great pressure, even if only slightly, and the surfaces of the pieces to be welded must tend to "wet" each other to an appreciable exteht in order to cohere. The best welding condition for iron and steel exists within a limited range of temperature.

It is for the purpose of describing in a general way the best and most economical welding systems and their applications that this book has been compiled, and it is our desire that all students of the art of welding may profit as much as possible through their study of this subject.

METALS AND THEIR NATURES

Since iron and steel are the most useful metals, these will be considered first.

Iron. Iron is rarely found native, but in combination with other substances, in which state it is known as iron ore. The metal is separated from the ore by melting. The ore is placed in a blast furnace, in layers alternating with fuel (coal, coke, or charcoal), with a suitable flux (usually limestone), and submitted to intense heat. The ferrite in the ore is melted and drawn off from the bottom of the furnace. This molten iron is then run into molds to form the pig iron of commerce.

Cast Iron. If pig iron is melted in a cupola and cast into molds the product is called "cast iron." In this smelting process the iron takes an appreciable amount of carbon from the fuel and consequently it is hard, brittle and granular in composition. It is fusible, but cannot be welded or forged. It is largely used in the manufacture of machinery. The amount of the carbon content can be reduced to suit requirements by "burning it out."

A strong blast of heated air is forced through the iron while it is still molten; the oxygen in the air combines with the carbon and carries it off in the form of carbonic-acid gas ($C O_2$).

Charcoal makes the best fuel for the smelting, as it is free from sulphur and other impurities. It is used in making the fine quality of iron called Swedish iron. Good charcoal iron is easily welded and will stand more bending without breaking than any other kind of iron.

Wrought Iron. Wrought iron is almost entirely free from carbon and is very malleable and ductile, hence easily welded. Very little of it is obtainable.

Steel. Steel is a variety of iron intermediate between cast iron and wrought iron containing an appreciable percentage of carbon. When tempered it is tough, hard, and elastic. It is made by simply stopping the air blast when making iron and leaving a small amount of carbon in the metal. While wrought iron is slightly fibrous, steel is crystalline, and the best quality is homogeneous throughout.

Soft Steel. Soft steel, or "mild" steel, as it is called commercially, is steel with very little carbon. It is extremely ductile and is used in the manufacture of boiler plates. When it is made by forcing air through the molten iron to burn out the carbon, as described, it is called "Bessemer" steel, after the inventor of the process. Whenever it is necessary to recarburize the metal, this can be done by adding a cast iron called spiegeleisen, containing both carbon and manganese, the latter of which enables the iron to hold a larger amount of carbon and adds to its strength.

Open-Hearth Steel. Cast iron melted in an "open hearth" or broad, shallow furnace with scrap wrought iron or steel and iron ore produces open-hearth steel, a very tough steel, also used for boiler plates and similar articles.

The Percentage of Carbon in Steel. The amounts of carbon in iron and steel are approximately as follows:

Cast Iron	3 % to 4.5%
Tool Steel	.5% to 2 %
Mild Steel	.1% to .5%
Wrought Iron	Less than .1%

Steel Castings. Steel castings are usually made of mild steel and contain small amounts of manganese, silicon, sulphur, and

phosphorus in addition to the carbon. Manganese and silicon improve the steel, but sulphur and phosphorus are not desirable. Aluminum is sometimes added before the castings are poured, as a solidifier or deoxidizer, and it improves their quality. The amounts of these elements in steel castings usually vary as follows:

Carbon	.18% to .75%
Manganese	.30% to .80%
Silicon	.27% to .33%
Sulphur	.032% to .056%
Phosphorus	.032% to .092%
Aluminum	Traces only after melting

Steel Alloys. The various elements used to alloy iron are technically known as "impurities," even though their addition is a distinct advantage. All the alloys of iron and steel may be welded by the modern processes, but not all can be welded by the old blacksmith methods.

Silicon, on account of its crystalline structure, makes the steel brittle. A high percentage of it prevents welding, but a small quantity of manganese added to the alloy tends to overcome this difficulty.

Manganese reduces both the sulphur and oxygen in the iron and adds greatly to its strength. It should not be present in large quantity, however, as more than 1.5 per cent makes the metal brittle and prevents welding.

Nickel increases the tensile strength of the steel without impairing its elasticity; it also tends to prevent rusting of the metal. Nickel steel may be welded, and the addition of nickel up to 5 per cent is safe, if the amount of carbon is kept small.

Chromium combined with steel forms the alloy *chrome steel.* It is fine grained and very hard, and can be successfully welded.

Copper. Copper is one of the metallic elements. It is found as an ore and in a pure state. The ore must be smelted and the copper refined before it is ready for use. It should be at least 99.5 per cent pure and entirely free from sulphur. It is used largely in the form of sheets, bars, and tubes; occasionally it is cast in molds like iron and steel.

Copper Alloys. Copper is the principal element in brass, bronze, gun metal, and many other alloys, and is nearly as useful to man as iron. It can be welded readily by any method, though

brazing and soldering have been the processes generally used for joining or repairing pieces of it. Great care must be exercised when casting and welding copper to insure its being properly deoxidized. Silicon, aluminum, and phosphorus are used for the deoxidizing. Alone, aluminum has the disadvantage of oxidizing too rapidly when exposed to the air.

Bronze. Tin and copper form a good alloy called "bronze," which is harder than either metal alone. The addition of tin increases the fluidity of copper but diminishes its ductility. The strength of copper is increased by adding up to 12 per cent of tin, and its crushing strength is increased by additions up to 18 per cent of tin. Beyond this latter point the bronze becomes hard and brittle. "Gun metal" is copper with from 8 per cent to 20 per cent of tin; the best alloy contains about 10 per cent of tin. Great care must be used when welding alloys containing tin, as the latter melts at a comparatively low temperature and may easily be burned in the welding.

Brass. Zinc and copper form the alloy known as "brass," and 40 per cent of zinc may be used without serious effect on the malleability or ductility of the alloy, but more zinc makes it very brittle. Tin is sometimes added to brass to increase its strength. Zinc is a good deoxidizing agent for copper but it vaporizes quite rapidly at high temperatures. This causes it to pass out of the alloy, leaving it porous or spongy; this is why brass is so hard to weld satisfactorily. Lead is also used as an alloy for copper but not over 3 per cent can be used, as it does not mix well.

Manganese Bronze. Manganese is alloyed with copper in various proportions. This alloy, known as "manganese bronze," may be both forged and welded by proper methods, although welding is a rather hard process to perform satisfactorily with it. It is very ductile and strong and does not corrode easily, even in salt water. It weakens slightly when heated and shrinks more than gun metal; hence it requires special care during welding operations.

Phosphor Bronze. Phosphorus with copper makes a strong alloy which resists corrosion. The percentage of phosphorus used when making phosphor-bronze castings ranges from two per cent down to but a few hundredths of one per cent. Frequently the phosphorus causes hard spots because it does not always combine

freely and thoroughly. This alloy is also hard to weld readily, although the welding may be done by proper methods.

Aluminum. Aluminum is the most abundant and the lightest of the commercial metals. It is very valuable for forming alloys but it is rather hard to weld or solder because of the rapidity with which it oxidizes, especially at high temperatures. Castings of aluminum are successfully welded, however, by several methods; and sheets of aluminum are welded by the gas methods. The various alloys are also welded; the heat conductivity is comparatively high and the metal acts like solder when melted. It melts at 655 degrees centigrade, and is easily burned. A sort of scum forms on the surface, if the welding is done with a high-oxygen flame. Although gold, silver, platinum and a few other metals may be welded, commercial welding is almost confined to the metals here described, and the characteristics of these metals, especially of iron, steel, and copper, are most important to remember in connection with commercial welding and manufacturing.

WELDING PROCESSES

Classification. There are numerous processes for welding metals, and these may be divided into four main classes—electric welding, gas, or hot-flame, welding, chemical welding, and smith welding, or forging. There are several allied operations for joining metals, namely, soldering, brazing, and riveting.

In order that the student may know something about all methods of welding, and about joining metals by the several processes, short descriptions of the more important ones are given, so comparisons may be made between the various processes and their applications. More complete data may be found in other books issued by this institution, and should be referred to by students desiring to go more completely into any phase of the subject. The following information will also be of value in determining which of the several processes would be suitable for any special work the student may have in hand to be done.

Electric Welding. Electric welding has recently been developed commercially to such an extent that it is rapidly coming to the front as the most important of all the welding processes. Six different systems have been developed for using electrically gen-

erated heat for welding purposes. These are the Benardos, Slavianoff, Percussive, Thomson, Zerener, and LaGrange-Hoho systems. The first four are of chief importance.

The *Benardos system* employs a piece of carbon or graphite as one electrode of the arc; the arc is drawn between the carbon and the work (which is the other electrode), and the heat of the arc melts the filling material required for joining the pieces.

The *Slavianoff system* consists in drawing an arc between the work and an electrode, but in this case a piece of the filling material is used as one of the electrodes, which melts directly into place on the job. This is the most important of the electric-welding processes, although but recently developed to a commercially practicable point. It is applicable to practically every class of welding and for nearly all metals.

In the *Zerener system* two pieces of carbon are employed. The arc, or flame, is deflected toward the work by means of a magnetic field and the filling material is thus melted.

The *Percussive system* was developed as the result of experiments in welding aluminum wire. The apparatus consists of a moving holder for the wires, which are connected across the supply circuit with a condenser in parallel and so arranged that a rush of current takes place across the point of contact or joint when the wires are forcibly brought together. This process is now in use for welding the many kinds of metals used in the manufacture of small parts.

The *Thomson system* requires the use of alternating current, whereas the other systems generally use direct current for welding. In its latter-day modifications it consists in bringing together the two pieces to be welded, in a special machine, passing an alternating current through the point of contact until the parts are heated sufficiently to be soft, and then squeezing them together until they unite. The heating is due to the resistance of the joint to the electric current.

The *La Grange-Hoho system* also is based on resistance. The pieces of metal to be welded are placed in a bath of electrolyte, which conducts the current from a positive electrode. The actual weld is made by hammering, the same as in smith-welding, after the metal is hot and soft. This is not at present a very important

process commercially. In the three other processes the electric arc furnishes the heat, and additional material is used to join the pieces.

Gas Welding. Gas welding, or hot-flame welding, is at present next in importance to smith welding. It is applicable to many kinds of work which cannot be done by forging. The three most important processes commercially are known as the oxy-acetylene, oxy-hydrogen, and blau-gas. All these processes consist in using oxygen and another gas to give a flame of sufficiently high heating capacity to melt the material to be welded. The gas used with oxygen is indicated by the name of the process.

Chemical, or Thermit, Welding. Chemical welding is practiced today almost exclusively by the process known as "thermit welding." Aluminum in fine grains or filings is mixed with some metallic oxide, usually of iron. On being heated by a priming the aluminum combines so rapidly with oxygen of the oxide as to generate intense heat, which sets free the iron from its oxide. The fluid thus produced forms what is known as a "cast-weld," which is very strong and is much used in welding large articles.

Smith Welding. Smith welding, or forging, is the process of shaping or joining metals by hammering or pressing the pieces together. It may be done either with or without heat. It is the most common of all the welding processes, and depends upon the skill of the operator more than the other processes of welding; hence it is gradually being superseded by them.

Brazing and Soldering. Brazing and soldering are processes which approach welding so closely in some of their applications that they are worthy of serious consideration as a part of that subject.

Brazing consists in joining pieces of metal by fusing them with an intermediate material called "spelter," the surfaces of the joint having been previously prepared with a suitable flux. When brass is brazed, the process really becomes welding, since brass is the principal constituent of spelter. The heat is produced by a gas flame and the work is done at a comparatively high temperature.

Soldering, or "metallic gluing" as it has been called, is done with a soft alloy, which is melted and used somewhat as glue in the space between the parts to be joined. Soldering can be done

with a gas flame or a heated soldering copper and at comparatively low temperatures. Soldering is a comparatively old process, is cheap, easily learned, and in wide use, but it should not be used for any joint requiring much strength.

Riveting. In joining metal plates and sheets small malleable pins or bolts are passed through the parts to be joined and then flattened into a head at each end to make them tight and secure. This process is also old and will be described in detail later in order to bring out the comparison between this and the newer methods of joining materials.

Miscellaneous Processes. Several other processes of joining metals have been invented, among them the "Ferrofix" for brazing and Laffitte for welding. Neither of these last is in very wide use.

ELECTRIC ARC WELDING AND CUTTING

Historical. The use of the electric arc as the source of heat for melting and joining metals is one of the oldest applications of electricity, and yet it was not developed to a commercially practicable point until within comparatively recent years. In 1786, Martinus van Marum published at Leipzig, a book, describing some early electrical experiments, and, in this book, he gave an extended treatise on the melting of metals by means of the electric current. In 1810, Sir Humphry Davy, the versatile English scientist, described some experiments made in London with various metallic bodies, and, in 1815, J. G. Children of London described a process for welding iron wire with the electric arc obtained from batteries. From then until now, the development of the art of electric welding has steadily progressed. Today the electric is the chief welding method, and it is being rapidly adopted for all classes of metal manufacture and repair. The men who have done most to perfect electric-arc-welding processes are De Meritens, Benardos, Olszewsky, Coffin, Zerener, Slavianoff, Howard, and a few others of lesser importance.

Characteristics of the Electric Arc. The electric arc has probably been given more careful study and investigation than any other electrical phenomenon, and yet there is comparatively little exact knowledge available regarding some of its most important characteristics. The exact temperature of an arc has never

been determined, although the most refractory substances may be melted in its vapor. The temperature has been variously estimated at from 2,000 degrees centigrade by some scientists up to 6,000 degrees centigrade by others, but the temperature generally accepted as correct is about 5,000 degrees centigrade. As long ago as the year 1840, Grove discovered that the current flows more easily from metal to carbon than in the reverse direction and that the current through an arc is greater, when passing from an easily oxidized metal to one that is not, than when flowing in the reverse direction.

The explanation of this is comparatively simple. The conductivity of an arc depends largely upon the kind of vapor in the arc and, to some extent, upon the ease with which the cathode (negative electrode) can be kept at a high temperature. If the anode (positive electrode) gives off a conducting vapor when heated this vapor will help the conductivity of the arc. In the arc-welding systems in commercial use today, the arc is drawn between metal and carbon, or between metal and metal, and, since the positive electrode of an arc reaches a higher temperature than the negative, it is more efficient to use the article worked upon as the positive electrode of the arc. Since iron is more easily vaporized than carbon, the current flows more easily from iron to carbon than the reverse, because there is more iron vapor than carbon vapor in the arc. This is proved by the fact that it requires more voltage to send a given current through an arc between carbon electrodes than between iron ones. It is also important that the negative electrode be kept at a high temperature, and the usual practice of having the negative electrode small (a wire or carbon pencil) makes this easily possible.

ARC WELDING PROCESSES

General Features. The process of welding or cutting with the electric arc is possible with nothing more than a source of current at a suitable voltage, some means for regulating the amount of current flowing, and an electrode. Practice has shown, however, that certain other devices are necessary, if satisfactory welding is to be done; and it is the determining of these devices and their proper uses that constitutes the main differences in the vari-

ous processes in use today. In order to do welding or cutting with the arc it is necessary first to connect the work to the positive side of the power-supply circuit and the electrode to the nega-

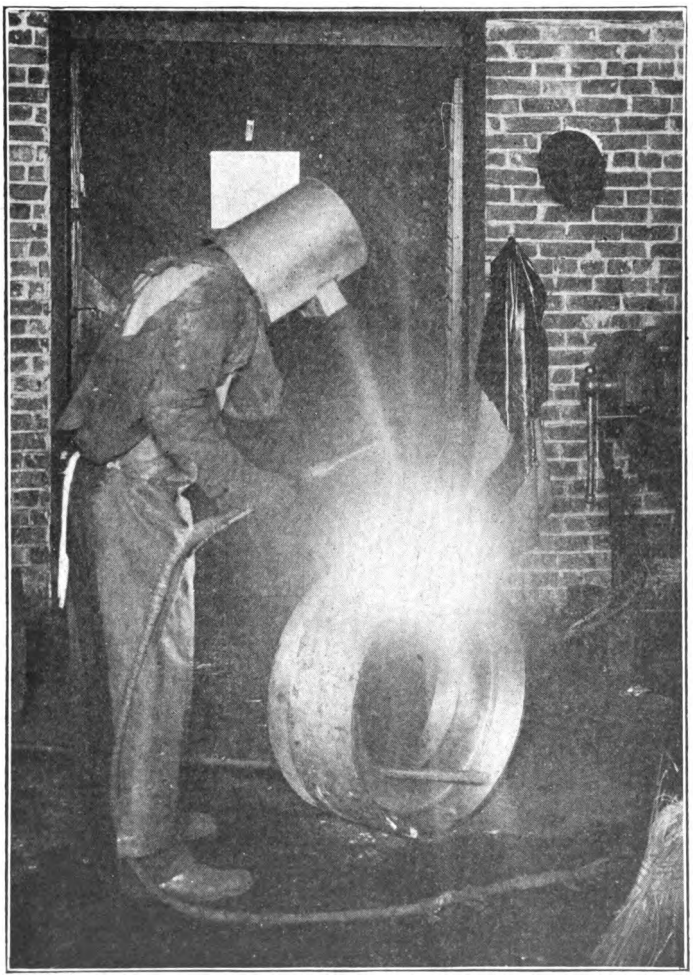


Fig. 1. Striking the Arc
Courtesy of Westinghouse Electric & Manufacturing Company

tive side of the circuit, by means of wires or cables, and to insert a regulating resistance in either of these circuits to limit the current to the proper amount. The negative electrode should then be placed in contact with the work and quickly withdrawn, to

establish the arc, Fig. 1. As this provides the temperature required, the metal soon begins to melt and the work begins.

In general, electric-arc welding consists in using the heat of the arc to fuse or melt the filling material into the place to be filled, Fig. 2, although if there is sufficient material in the article worked upon it may be melted down to fill the space. Two methods of employing the arc for welding are in commercial use today, the metallic and the graphite method. For the metallic-

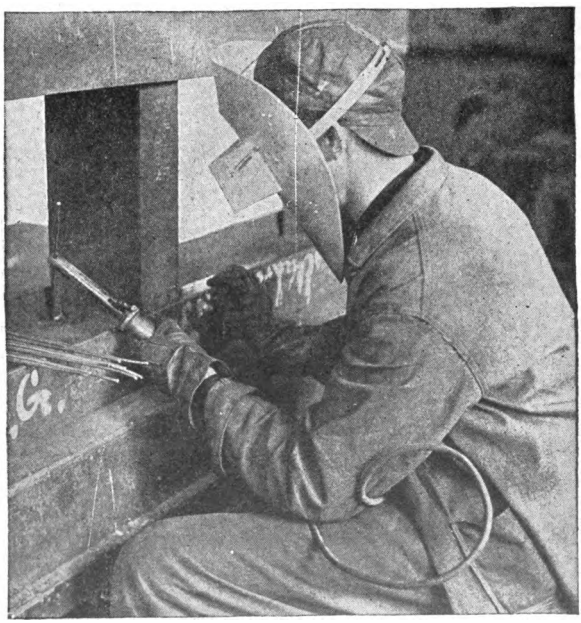


Fig. 2. Operator Using Metallic Electrode
Courtesy of C. & C. Electric and Manufacturing Company

welding method, Fig. 2, a piece of wire is used as the negative electrode of the arc, and this is fused upon the surfaces to be joined. For the graphite method, Fig. 3, a piece of carbon or graphite constitutes the negative electrode, and a separate piece of metal, fused with the heat of the arc, is used as the welding material. The graphite process is always used for cutting, a slot being melted through the piece to be separated. There is also a third system which will be described later, but it is not much used in the United States.

Using the Arc. To use the arc successfully, it is necessary to practice starting as well as using it, especially when working with the metallic electrode. The trick consists in touching the work and then getting away as quickly as possible to the required distance, and yet not so far away as to rupture the arc. If the electrode is of metal it will heat and fuse so quickly as to stick to the job unless withdrawn quickly, but the graphite or carbon electrode will not tend to stick and is easier to use. For metallic-electrode work the arc should be from $\frac{3}{16}$ to $\frac{5}{16}$ inch long (metal to

Fig. 3. Operator Using Graphite Electrode
Courtesy of C. & C. Electric and Manufacturing Company

job), according to the size of the wire used. The carbon arc should be about an inch long for ordinary work; it may be shorter for heavy currents and longer when less current is required. Small carbons may be obtained for lighter kinds of work and large ones for big jobs.

When working overhead on steel plates the arc must be kept shorter than when working down on the job or against a vertical seam. A slightly higher voltage and greater current will assist in overhead work. Cast-iron welding is best done by working in a horizontal position, with graphite electrodes; but steel castings and

forgings may be welded with metallic electrodes, in any position, although large welds can be finished more quickly by using graphite electrodes and heavier currents. The voltage required will be about the same in either case, though metallic arcs require somewhat lower voltages than carbon arcs. Experience will soon teach the good mechanic what current and electrode sizes to use for the various jobs and how to handle the work to the best advantage.

Care should be exercised to protect the eyes and face from the glare and heat of the arc, especially with the carbon electrode, because the chemical action results in concentrated sunburn. If the eyes should be exposed and afterwards feel "full of sand" a wet cloth placed over them for a few hours will relieve the distress. Ordinarily, no permanent injury results from ordinary "flashes." However, care is always to be taken. Suitable colored glasses mounted in head shields are the best protection, and gloves should be worn also. Many operators have been in the business for years and have not been injured; so arc welding is not to be considered dangerous.

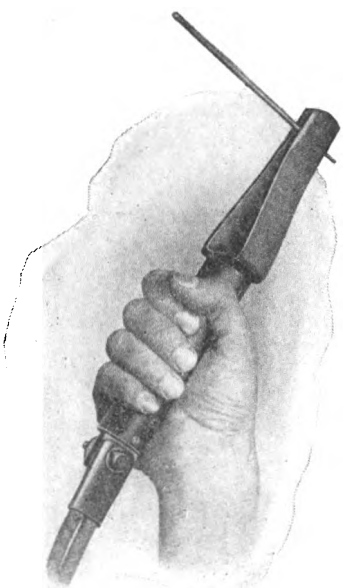


Fig. 4. Siemund Hand Electrode Holder
Courtesy of Siemund-Wenzel Electric Welding Company

Benardos System. In the Benardos system of electric welding a carbon pencil is the negative electrode and the article worked upon is the positive electrode; a continuous, or direct, current at a moderate voltage (usually from 60 to 70 volts) is employed. After the arc is established by touching the electrodes together, a piece of the filling material in the form of a "melt bar" is fused into place with the heat of the arc. Any metal, which does not volatilize or burn up too easily at the temperature obtained, may be welded by the Benardos process. This process is the best to use for cast iron, the copper alloys, and aluminum. When using the graphite pencil, it is necessary to give the hand a sort of rotary motion in order to cause the arc to play about over

the surface of the job and prevent burning, for the arc never stops melting the metal so long as it exists. This motion causes whatever slag or other impurity that may be on top of the molten mass to flow off to one side, instead of remaining in the weld and spoiling its quality, and distributes the heat uniformly over the piece welded. When cutting with the arc, the article to be cut should be so placed that work can begin at the top and progress downward across the face of it and the molten metal run off.

Slavianoff System. In the Slavianoff system of electric-arc welding a metallic pencil, Fig. 4, is used as the negative electrode, and the article worked on as the positive electrode, and a continuous current at low voltage is employed. After the arc has been established by touching the electrodes together and separating them, as before, the negative electrode itself begins to melt at the tip and thus forms the filling material. This system is more successful for work with iron and steel electrodes than with the other metals, although many of them may be used where high-class work is unnecessary. This system has been mainly applied to sheet-steel work, the metal electrode being deposited along the joint to be made and the two plates tied together so that they form practically one piece. This process may also be used for building up worn or missing pieces, filling holes, etc. The current required for the Slavianoff process is much less than that for the Benardos process but it is much slower and therefore less practicable for operations involving the placing of any very large amounts of metal quickly. The successful development of the Slavianoff system has been the principal cause for the recent rapid spread of electric welding in the industries.

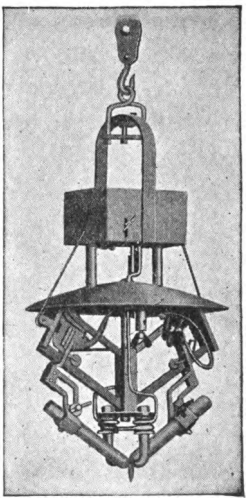


Fig. 5. Type of Zerener Welding Unit
Courtesy of Westinghouse Electric & Manufacturing Company

Zerener System. The Zerener system employs two electrodes made of carbon and mounted in a frame which holds them at an angle with relation to each other and to the work, Fig. 5. The arc is drawn between them and is then deflected downward by a

magnet and used in the same way as a gas flame. The apparatus for holding and feeding the carbon pencils is so bulky and complicated that this system has not been used in America to any great extent, although it is in use in several plants in Germany. The apparatus is of such a nature that large amounts of current cannot be used; so it is limited to comparatively light work. The holders for even moderate-sized work are so large and heavy that they must be suspended from above by ropes and moved about over the work. Small holders for use in one hand have been developed for welding only the lightest articles. The advantage claimed for this system is that owing to the magnet the arc can be deflected and finer work done.

Alternating-Current System. The alternating current for arc welding has recently been tried successfully. Electrodes or welding wires are coated with silicates to form a pocket around the arc and permit it to be drawn to practical working length. This system is based on the use of special transformers to supply current at proper voltage, in place of motor generators or resistances with direct current. It is expensive on account of the special electrodes required and the low power factor of the transformers used.

DIRECT-CURRENT WELDING EQUIPMENT

Simple Equipment Wasteful. The equipment required for electric-arc welding depends largely upon the nature of the work to be done. Of course, the most complete apparatus does the best work, as in the case of any sort of apparatus. The most elementary equipment consists of a barrel of water with two iron plates in it (the resistance of the water reduces the amount of current flowing), an electrode holder, and some cables to connect the parts to the power circuit. This system can be used for cutting and for welding where roughness and uncertainty of results are no disadvantage. The current is varied by varying the space between the plates in the water barrel but this system is very wasteful and inefficient because the line voltage (usually 220 volts in shops and 550 volts for street railways) must be cut down to that required for welding (about 20 volts in the arc); this is done by dissipating the unused energy in the form of heat in the water. Sometimes resistances, made up of cast-iron grids, Fig. 7, are used

instead of the water barrel, but they are more expensive and no more efficient. This grid resistance is cut into and out of circuit by a series of switches.

Advantages in Low-Voltage Generators. The use of dynamo-electric machines of low voltage, Figs. 11 and 15, instead of resistances as just described, is preferable because of their higher efficiency and the better voltage regulation obtained. Figure 6 shows a typical wiring diagram for the low-voltage equipment. It is well known among electrical men that a properly designed motor-generator set gives the best regulation of voltage and, when the generator is properly compounded, we have the ideal apparatus for electric welding. The leading systems in general use today

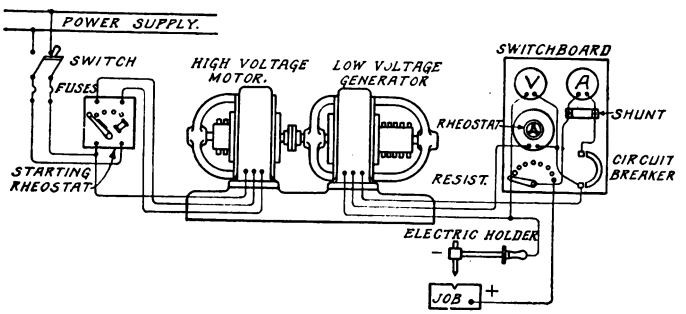


Fig. 6. Elementary D.C. Arc-Welding Equipment

consist of motor-generator sets with suitable control apparatus for motor, generator, and the welding and cutting circuits.

Single unit machines such as dynamotors, synchronous converters, etc., are also used, although the voltage regulation and current control are not quite so good as with motor-generator sets. For working with the graphite electrode and for the heavier classes of metallic electrode work they are all right, and a large number of them are in use in foundries, ship yards, railway shops, etc. A few of them are also being used in lighter work where the total load is not such as to cause a drop in voltage, and they make fine portable outfits because of their small size and light weight.

Manufacturers of Equipment. There are at present several companies in the United States offering electric-arc-welding outfits. One of these outfits has iron-grid resistance to reduce the voltage to the potential required for welding; most of them, however, use

low-voltage generators. The C & C Electric and Manufacturing Company was the first manufacturer in this field.

Among the others are the Westinghouse Electric & Manufacturing Company, the General Electric Company, Lincoln Electric Company, Burke Electric Company, Siemund-Wenzel Electric Welding Company, Crocker-Wheeler Company, Welding Materials

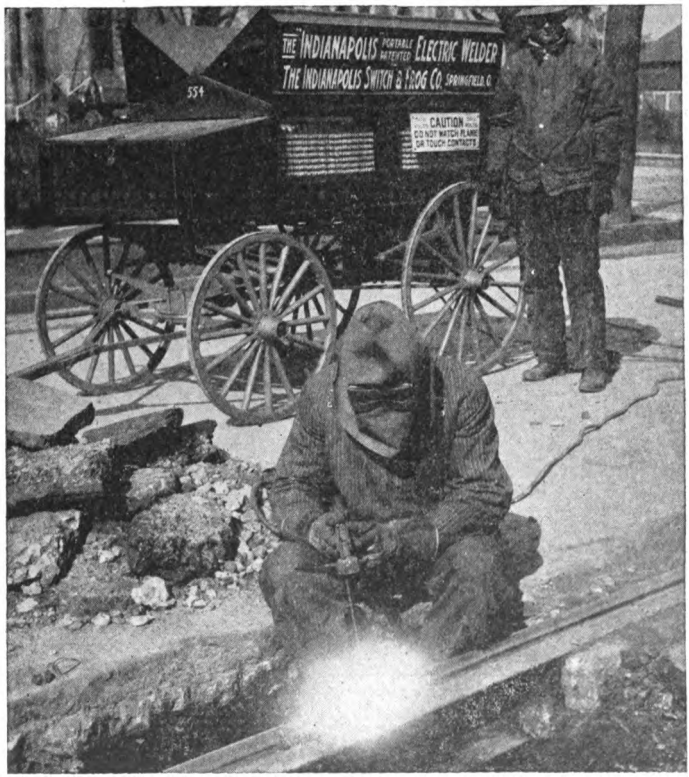


Fig. 7. Portable Electric Welder in Action
Courtesy of Indianapolis Switch and Frog Company

Company, Wilson Electric Welder Company, and the Triumph Electric Company. The Indianapolis Switch and Frog Company makes the resistance system mentioned.

Each of these companies offers its system on the strength of some peculiarity of the apparatus controlling the welding circuits, or certain features of the welding machines. Nearly all of them build constant-voltage generators, and some of them advocate con-

stant-current apparatus. A few offer machines and control apparatus to give both variable voltages and currents.

Indianapolis Track Welder. The Indianapolis Track Welder, Fig. 7, consists of a group of iron resistance grids mounted in a framework on a four-wheeled truck, with means for making connection with the trolley wire to get current. It is used almost entirely for repairs on street-railway apparatus and tracks. The control device consists principally of a set of switches for varying the number of grids in series with the arc, an electrode holder, and cables. The Slavianoff system is used for most operations, although the Benardos system may also be used. Owing to the low efficiency of operation they have not been adopted for use in

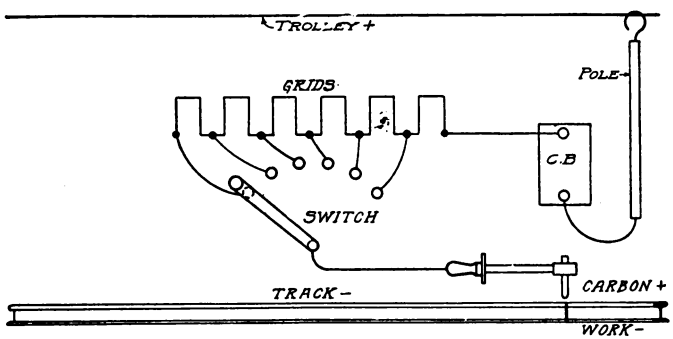


Fig. 8. Wiring Diagram Showing Principal Features of the Indianapolis Track-Welding System

industrial plants, but the cost is comparatively low and street railway companies do not seem to object to the enormous waste of energy incident to their use.

The diagram of connections, Fig. 8, shows the relation of the various parts of this equipment and the switches for varying the current by cutting in or out the grids of the resistance. This system, like that employing the water barrels, is such as to necessitate a separate outfit for each operator, who must adjust his current to suit the work in hand without interfering with the other operators.

Since it is true that street-railway circuits are of comparatively high voltage (from 500 to 600 volts), considerable resistance must be provided for cutting down the voltage; and on account of the amount of current required this resistance must be of rela-

tively large ampere capacity. This is why the outfits must be mounted on separate trucks as indicated, or upon railway cars.

Westinghouse Arc Welder. The equipment produced by the Westinghouse Electric Company consists of a motor-generator set with switchboards for controlling the machine and the welding circuits. The generator is a 75-volt compound-wound direct-current dynamo and is direct-coupled to a motor of proper capacity and suitable for operation from the power circuit available. Being a constant-potential generator, several operators may work from it at once if proper resistances and switches are provided for

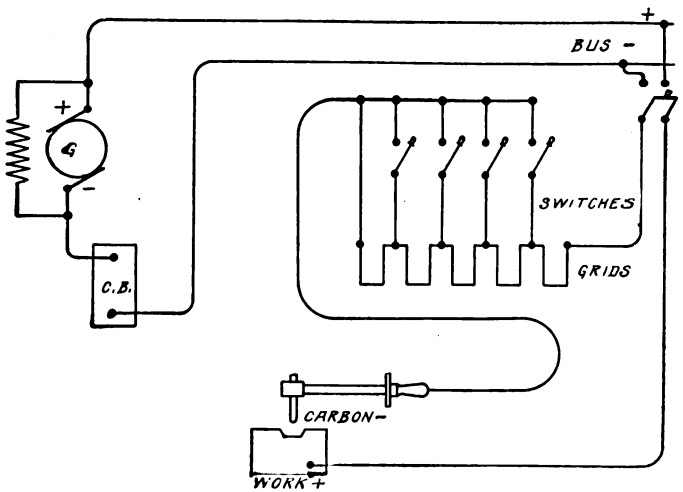


Fig. 9. Wiring Diagram for Westinghouse Arc Welder

each circuit, and work may be done by either the Benardos or Slavianoff process. An overload circuit breaker is provided to protect the generator from the effects of injurious overloads after welding has started. With this apparatus various classes of welding and cutting may be done. The positive line is connected to the work and the negative to the electrode holder in the usual manner. The diagram of this outfit is shown in Fig. 9.

The Westinghouse Company also makes a one-man outfit mounted on a small truck, for portable use. This outfit is a constant-current equipment, operating without external resistance. It will give any desired current between 125 and 200 amperes with

any voltage drop from 0 to 30 volts in the arc. The open-circuit voltage of the generator is about 55 volts, and the nominal rating is 175 amperes. Either metallic or graphite electrodes may be used.

Lincoln Arc Welder. The Lincoln Electric Company makes both motor-generator sets and single-unit machines for welding equipments, both being similar in operation to the Westinghouse outfits just described. The wiring diagram, Fig. 10, shows the general connections. The single-unit machines are made as synchronous converters for use on alternating-current circuits or as dynamotors for use on direct-current circuits. The Lincoln dynamotor differs from others in that there is but one commutator and

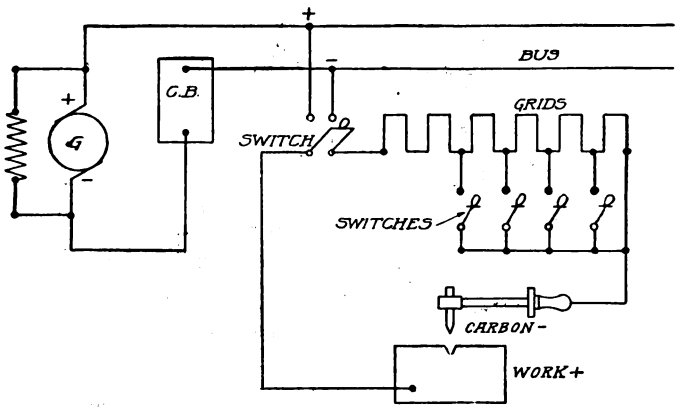


Fig. 10. Wiring Diagram for Lincoln Arc Welder

the outgoing or generator circuit is taken from two extra brushes located between the motor brushes in the proper position to give current at the proper voltage. The amount of current is regulated by varying the strength of the interpoles through switches and by lengthening or shortening the arc. Resistances are used for modifying the current from the alternating-current converters, and also from the motor-generator sets in the usual manner.

Switchboards are provided containing the apparatus for controlling the welding machine and welding circuits, and an overload circuit breaker is provided to protect the generator from dangerous overloads while working. The overload circuit breaker must be closed by hand if opened. The voltage regulation of the single-

unit machines is not quite so good as that on their motor-generator sets, but work requiring more efficient regulation is usually done by either the Benardos or Slavianoff system.

Siemund-Wenzel Arc Welder. This apparatus consists of a single shunt-wound, direct-current generator for each welding circuit, Fig. 11, and operates as does the Slavianoff system. The generator operates at full load all the time, and uses the current in the arc when welding or dissipating the energy through a resistance in the form of heat when not welding. The circuit is thrown from the arc to the resistance by means of a solenoid

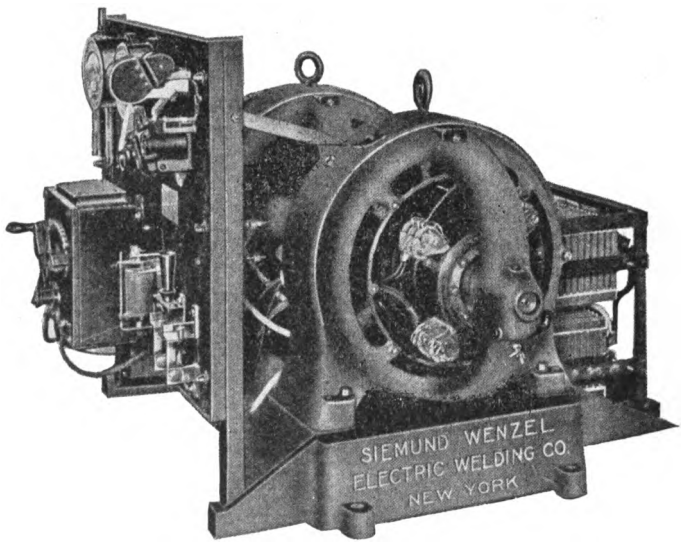


Fig. 11. Single Welder Siemund-Wenzel Unit

switch, and only one man at a time can work from one of these machines.

Varying the voltage at the generator alters the current to suit different jobs; varying the length of the arc also regulates the current and the amount of metal deposited. This system also uses an electrode holder with a coil embodied in the handle in such a way as to set up a magnetic field around the metallic electrode and arc, the theory of the makers being that this helps in depositing the molten metal in the weld, especially for overhead work. This is a doubtful advantage because molten iron and steel are practically non-magnetic at temperatures as low as 700° centigrade.

General Electric Arc Welder. The welding equipment developed by the General Electric Company consists of a compound-wound low-voltage direct-current generator, similar to those previously described, direct-coupled to a motor to suit the power supply, together with a switchboard containing the necessary devices for controlling the machine and the welding circuits. These equipments are made in portable form also, Fig. 12, the entire outfit being mounted on a truck.

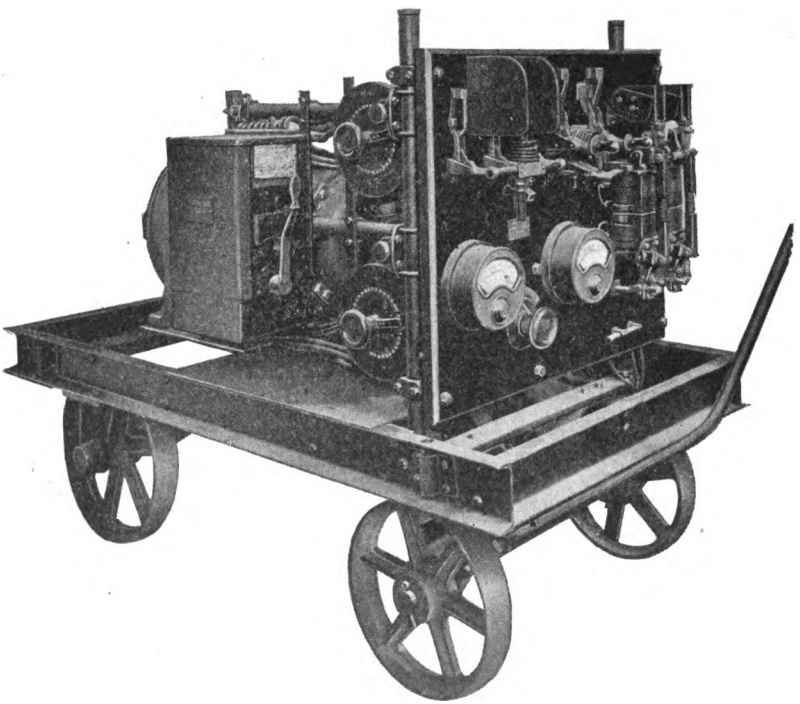


Fig. 12. Portable Welding Outfit
Courtesy of General Electric Company

By reference to Fig. 13, it will be seen that the current from the positive side of the generator flows to the work through a bank of resistance grids; from the work it passes, by way of the arc, electrode, and relay, back to the negative side of the generator. The contactor opens and inserts resistance in case the relay is actuated by an overload, since the amount of current required in the arc for welding is varied by a multiple contact switch which cuts in or out sections of the grid resistance. Because

of the constant-voltage system, several men can work at once from machines of this type by adding enough circuit-controlling relays and contactors. The overload relay described prevents injurious overloads on the generator; the only limitation to current flow in the individual welding circuits of multiple-circuit equipments lies in the resistance in use at the time of operation. In Fig. 14 is shown an operator using the graphite electrode on medium work.

C & C Electric-Arc Welder. The C & C apparatus for electric-arc welding has been longer in developing than any of the others have been. The C & C Company was the pioneer in this

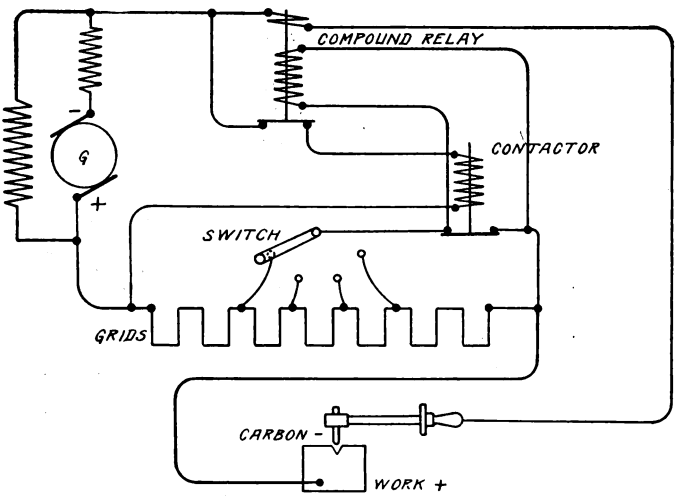


Fig. 13. Wiring Diagram for General Electric Welding System

field in America and, consequently, has its control system developed to a high degree and protected by numerous patents. The welding machine consists of either a single-unit machine or dynamotor for use on direct-current circuits, or a low-voltage compound-wound, direct-current generator of high overload capacity direct-connected to a motor of proper size and suited to the power supply. Both machines are mounted upon a substantial cast-iron base as indicated in Fig. 15. For controlling the motor and generator, a switchboard is supplied which may be mounted in any convenient position with relation to the machine and connected to the power circuit. On this panel are mounted the necessary instruments and switches for

the welding machine and motor; the apparatus for controlling the welding circuits is usually mounted upon separate smaller panels,

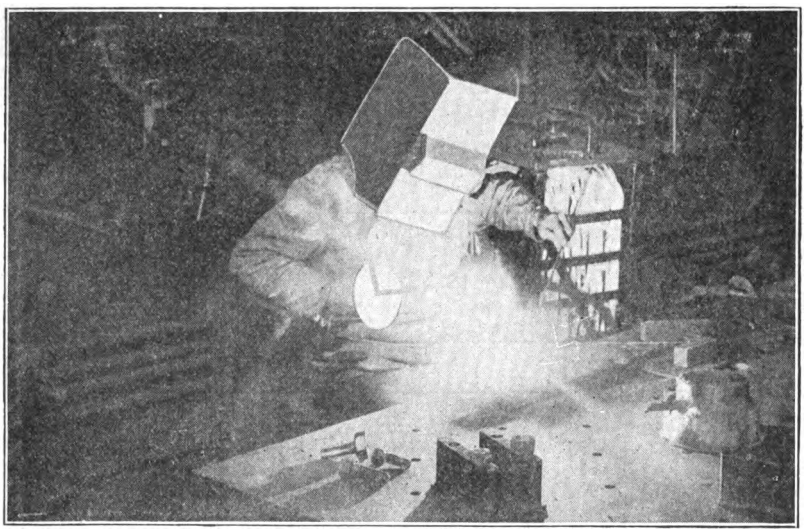


Fig. 14. Operator Using Graphite Electrode on Medium Work
Courtesy of General Electric Company

although for portable equipments or single-circuit outfits everything is mounted on the main switchboard panel.

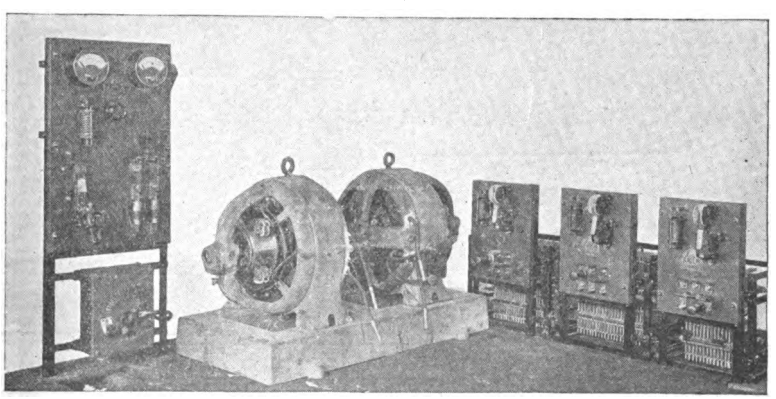


Fig. 15. 300-Ampere Welding Set with Control Panel and Auxiliary Welding Panels
Courtesy of C. & C. Electric and Manufacturing Company

Each welding-circuit control panel contains one of their patented automatic control outfits, and means are provided for

preventing a rush of current when drawing the arc as well as for inserting a protective resistance to reduce the current in case of overload when using the graphite arc. By this means the thinnest metal, Fig. 21, or the heaviest sections, Fig. 26, may be welded safely and smoothly with equal facility, and the operation of the controlling devices is so entirely automatic that the operator does not have to go to the switchboard and close circuit breakers or other devices after once starting work. This system of welding

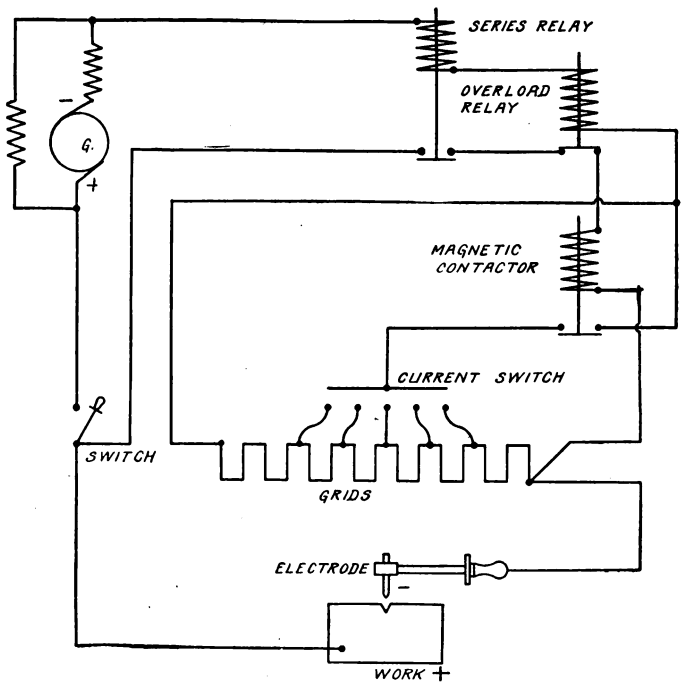


Fig. 16. Wiring Diagram for C. & C. Welding System

has been developed for working by either the Benardos or the Slavianoff system.

By referring to the diagram of connections, Fig. 16, it will be seen that the current flows from the positive side of the generator to the job, through the arc, electrode and holder, resistance, overload and series relays, and back to the negative side of the generator. The diagram shows the positions of the various items before the arc is drawn, and it will be noted that all the resistance

is in series with the electrode and other devices. The arc will, of course, be drawn between the electrode and the work in the usual manner, and it will be noted that the coil on the magnetic contactor is so connected as to be in shunt or parallel with the arc. When contact is made between the electrode and work to establish the flow of current and strike the arc, the coil of the series relay will be energized and it will close and energize the coil of the magnetic contactor. The contactor will not close, however, until after the electrode has been removed from contact with the work and the arc has been formed, since that contact is of lower resist-

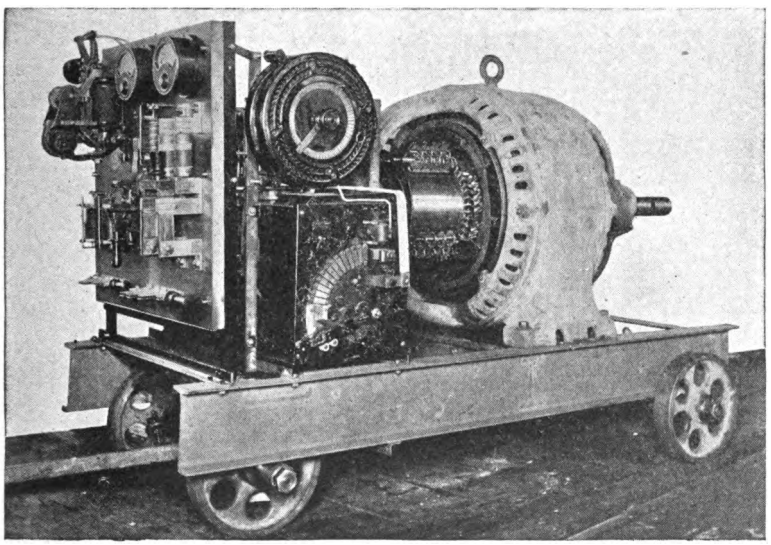


Fig. 17. 600-Ampere Portable Single-Unit Welding Outfit
Courtesy of C. & C. Electric and Manufacturing Company

ance than the coil in shunt with it. So long as the magnetic contactor is open, all the grid resistance is in circuit and the flow of current is too small to burn the work or overload the generator. As soon as the arc is drawn, that path becomes of higher resistance than the path through the shunt coil on the contactor, hence the magnetic contactor coil gets current enough to close the contactor and cut out resistance until enough current flows to suit the job in hand as predetermined by the setting of the resistance switch. In case of overload while working, the overload relay open-circuits the coil of the magnetic contactor and causes it to

open and re-insert the entire resistance, cutting the current to the minimum without rupturing the arc.

Owing to the use of a separate panel for each welding circuit, it is possible to have as many operators working at once as conditions require, tapping the panels off the distribution circuit from the machine panel the same as would be done with so many motors from any other circuit.

In addition to the constant-voltage apparatus just described, the C & C line includes a variable-voltage welding outfit for use when but one operator is to work from the machine. This consists of a differentially-wound compound-generator driven by a suitable motor, with proper controlling devices mounted upon a switchboard panel. This outfit maintains high efficiency even with a drop of 12 volts in the arc. The generator voltage varies automatically to keep the current constant at the predetermined value, regardless of the arc-length. A portable outfit is shown in Fig. 17.

The manufacture of C & C welding apparatus has recently been taken over by the Burke Electric Co. of Erie, Pa., and will be continued by them under the old patents as described above.

Welding Materials Company Outfit. This company has recently brought out a machine, to replace one formerly handled by them, based upon the use of a compound-wound generator of the variable-voltage constant-current type having an auxiliary exciter. This exciter is provided with a special differential winding, which changes the voltage supplied to the main generator field. Therefore, the action of the welding current in the end automatically regulates the voltage of the main generator so as to keep the current constant and at the predetermined value regardless of variations in the resistance of the welding circuit. The proper current for the work in hand is obtained by regulating the field of the machine before starting work, after this it is kept constant by the machine.

Other Equipment. An English system known as the "quasi-arc method of welding" has been used to a limited extent abroad, but has not been received very kindly in America because of its expensive electrodes. It is based upon the use of wires or electrodes coated with a flux to prevent oxidization. It can be used

on either direct- or alternating-current circuits. The Kjellburg system is also based upon the use of a flux on the wire, and the users of it make some very strong claims for it, but experience shows that work can be done successfully without flux. With both the above types of electrodes, any of the apparatus described may be used.

ALTERNATING-CURRENT WELDING EQUIPMENT

Use of Transformers. The use of alternating current directly in the arc for welding is a comparatively recent development, although alternating currents have been employed for butt welding

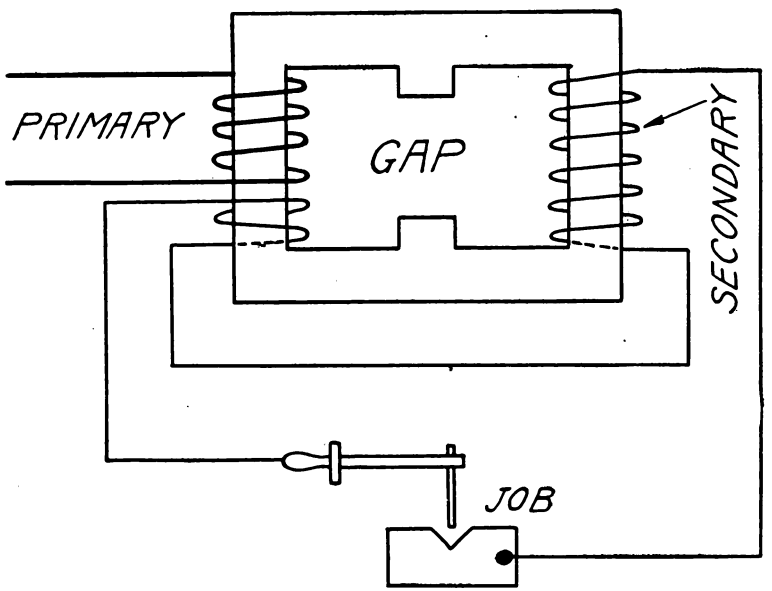


Fig. 18. Elementary A.C. Welding Outfit

for nearly a half century. The alternating-current arc, taking current direct from a transformer, was tried by the author several years ago, but, on account of the breaking of the arc at every reversal of flow, it was not found practicable. Investigation showed that a coated wire, described on page 28, made it easier to maintain the arc, and the subsequent development of suitable transformers finally made the alternating-current arc practicable.

For arc welding, the transformer is made somewhat as indicated in Fig. 18, thus insuring large leakage reactance and

producing a drooping power curve similar to that of a differentially wound, separately excited direct-current generator. This means that when the voltage rises the current falls, thus reducing the total power taken from the transformer and preventing dangerous overloading. It will be noted that there are two projections on the inner sides of the transformer core, between the coils, thereby forming an air-gap across which magnetic lines may leak in case of excessive excitation or magnetization of the core. It is this construction that makes regulation possible.

A part of the secondary winding is carried around the primary leg of the transformer core in such a way as to limit the maximum voltage developed in case of short circuit when the arc is starting or in the event of accidental contact when welding. If the amount of current used in the welding circuit increases, part of the magnetic flux is forced across the air-gap mentioned and the voltage automatically reduced until a proper balance is obtained. This prevents excessive currents in the welding circuit and insures better work.

Cost. Since no regulating or ballasting resistance is required with a transformer for welding, its energy efficiency is high, but, on account of its high leakage reactance, its power factor is low. The first cost of such apparatus is lower than for a direct-current outfit of similar capacity, but on account of the low-power factor it is necessary to provide so much primary capacity in the form of line copper, generator and transformer capacity, etc., that its total cost makes it prohibitive, except in such plants as already have more capacity available than is required for other purposes. For alternating-current welding with metallic electrodes, it is necessary to use coated electrodes to obtain satisfactory work, and this makes it more expensive than when plain wire is used. The electrode holders, control panels and other items of equipment may be the same as those used with direct-current outfits, and the work done should be about equally satisfactory.

Where alternating current is not available, which will be very seldom, it will be necessary to install an alternating-current generator with suitable driving motor, but in most places alternating is available. If a small amount of welding is to be done, a transformer outfit may be used to good advantage and at low cost for

temporary purposes. Coated electrodes are easier to use than plain ones, and it pays to use them when learning, even though they be discarded afterwards in favor of the lower priced uncoated electrodes. With coated electrodes there is less oxidation of the metal in the weld, on account of the exclusion of the air, and the required fusing or welding temperature is not so high as with plain ones, but oxidation is not very serious with uncoated electrodes, and may be ignored. The voltages are about the same as when direct current is used, and the total power required per pound of metal deposited per hour is the same. A transformer makes a very easily portable outfit for welding, so further developments along this line may be looked for.

WELDING OPERATIONS

Amount of Current Used. The various welding operations take different amounts of current, according to the nature of the material worked upon, the size and shape of the piece, and the sort of operation to be performed. For example, thin steel sheets, Fig. 19, require less current than thick ones; cutting requires a larger amount of current than welding, etc. Metallic welding operations usually require from 50 to 150 amperes, although thin sheets may be welded with 15 amperes and extra heavy ones may take 185 or 190 amperes; graphite arc welding, on the other hand, ordinarily requires from 350 to 500 amperes, though only 100 amperes may be needed for small articles and as much as 600 amperes on heavy work. Cutting with the electric arc requires from 300 amperes, on small sections, up to 1000 amperes or more, the average job taking from 400 to 600 amperes. The nature of the equipment supplying the energy will affect the amount of current required to some extent, those equipments with the best control systems being the most economical.

Plate Welding. The rate at which welding can be done depends upon the article to be welded, its size and shape, material, nature of the weld, etc. Table II indicates the speed of welding seams in sheet steel.

The figures given in the last column are only approximate, and may easily be exceeded by an expert operator, but they give a fair average. These apply to seams made by butting the edges

TABLE I

Data on Steel Plate Welding

Thickness	Diam. Electrode	Amperes	Seam Welded
28 to 20 gage	18 B. W. G.	10 to 25	30 ft. per hour
18 gage to $\frac{1}{8}$"	$\frac{1}{16}$" diam.	20 to 40	25 ft. per hour
$\frac{1}{8}$" to $\frac{3}{16}$"	$\frac{3}{32}$" diam.	30 to 60	20 ft. per hour
$\frac{3}{16}$" to $\frac{1}{4}$"	$\frac{1}{8}$" diam.	50 to 100	15 ft. per hour
$\frac{1}{4}$" to $\frac{3}{8}$"	$\frac{5}{32}$" diam.	75 to 150	10 ft. per hour
Over $\frac{3}{8}$"	$\frac{5}{32}$" diam.	150 to 180	Variable

of the plates together and welding along in the space between them. The edges of the heavier plates should be beveled suffi-

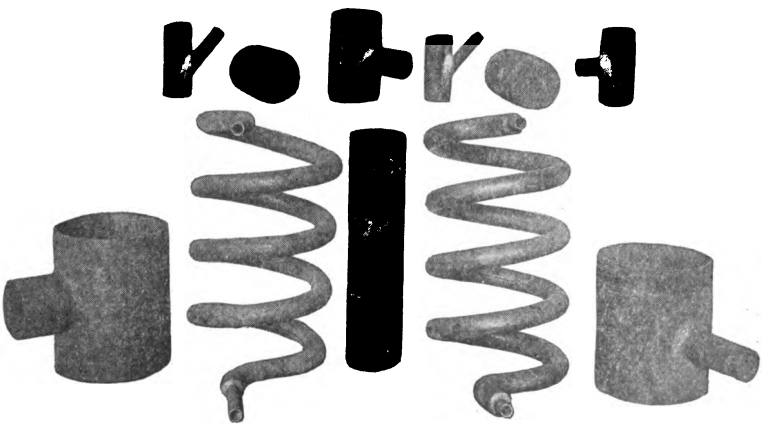


Fig. 19. Miscellaneous Pipe Welds with Light Tubing
Courtesy of C. & C. Electric and Manufacturing Company

ciently to allow the filling material to penetrate to the full thickness of the plates; otherwise a satisfactory weld will not result. Thicker plates than those given may also be welded and the time will vary as the square of the thickness. The estimate is based upon one-fourth of an inch as the standard because that is about the thickest plate which may be satisfactorily welded by going along the seam but once. For thicker plates it is necessary to go along the seam several times in order to fill the slot properly and the area of the slot increases approximately as the square of the thickness when a V-shaped groove is to be filled. When an X-shaped slot, or two V-slots, can be formed by beveling the plates on both sides, then the time required to make the weld is cut in

two, and the rate of speed varies in about the same ratio as the thickness of the plates. The metallic electrode is used almost exclusively for steel plate and sheet welding, although the graphite electrode is sometimes used for heavy plates, when it is possible to work with the plates laid in a horizontal position, thus preventing the molten steel from running off.

To Weld Castings. When castings of iron or steel are to be welded, it is necessary to provide enough space for the welding material, Fig. 26; otherwise it will be impossible to join the pieces throughout their thickness, because the filling material is not so liquid as that used with brazing and consequently will not flow in a small crack. With steel castings, and for some classes of small holes in large iron castings, the metallic electrode may be used, but for

Fig. 20. Arc-Welding Lug on Steel Casting
Courtesy of Westinghouse Electric & Manufacturing Company

most cast-iron pieces and very large steel pieces, it is necessary to use the graphite arc and a melt bar for the best results. For cast-iron welding it is desirable, owing to the high-shrinkage property of the metal, to preheat all but the smallest and simplest pieces before welding. This obviates cracking when the weld is cooling. It is also well to reheat after welding and allow the piece to cool slowly in order to insure a weld soft enough to machine. A good welding flux is also an advantage when making cast-iron welds, as it helps to raise the slag and improve the quality of the weld. Iron with about 25 per cent of silicon should be used for cast-iron welding, and steel with from 25 to 40 per cent excess of carbon, manganese, vanadium, or other desired content should be used when welding steel castings containing the elements mentioned.

Welding Copper and Aluminum. Copper and aluminum sheets, bars, and castings may be welded with the electric arc by using the graphite electrode and puddling in the filling. This operation is similar to welding cast iron and can be done only with the work laid in a horizontal position to prevent the welding material from running. Owing to the necessity for using the graphite electrode instead of a piece of wire, it is evident that thin sheets cannot be successfully welded by the electric-arc process. But sheets over one eighth of an inch thick have been welded, both of aluminum and copper, and castings as thin as one-fourth of an inch also. It is necessary to build a simple mold

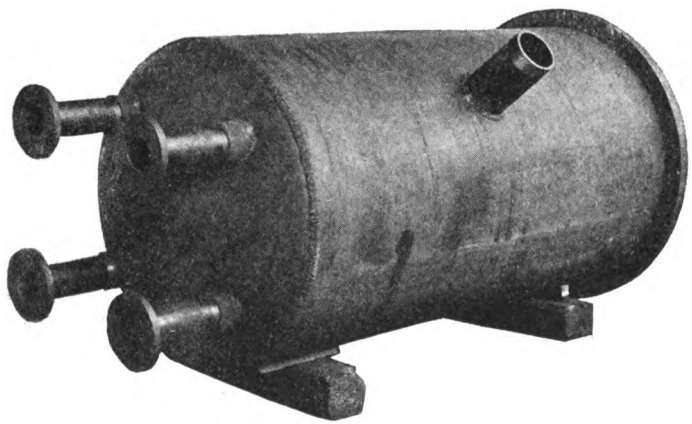


Fig. 21. Tank with Head, Flange and Connections Welded in Place
Courtesy of C. & C. Electric and Manufacturing Company

of clay around the spot to be welded in order to hold the molten metal, but the process is very simple and requires but the smallest amount of current to melt the metal. Large amounts of current tend to burn the material and, if zinc is present (as in brass), it will volatilize or burn out and leave a porous and useless weld. The same thing applies, but in a lesser degree, to bronze alloys containing manganese, phosphorus, etc. In other words, when welding alloys of any kind, it is necessary to use that current which is suited to the most fusible element in the mixture. The others will get heat enough to flow sufficiently for all practical purposes in most cases and experience will soon show any operator the best methods of handling any of the alloys.

Work on Boilers and Tanks. Boilers and tanks offer one of the best fields for the application of the Slavianoff, or metallic welding, process and this method is being adopted for manufacturing, Fig. 21, as well as repairing such articles instead of riveting them. Joints which have been properly welded with a metallic electrode of suitable size and composition and with the right amount of cur-

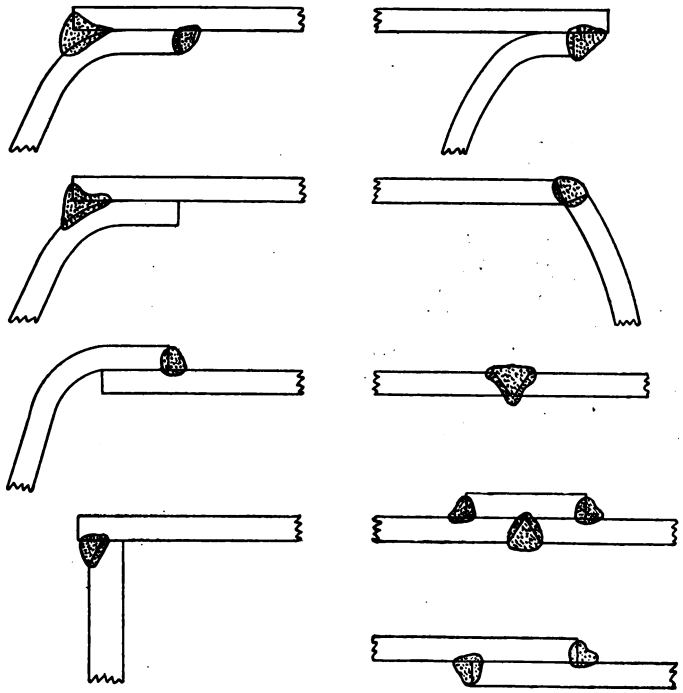


Fig. 22. Methods of Making Welded Seams in Tanks
Courtesy of C. & C. Electric and Manufacturing Company

rent will be stronger than riveted seams in metal of the same thickness. If the joint is reinforced slightly by additional filling material, it will be stronger than the original plate, but, even when ground flush with the thickness of the plates, it will show from 85 per cent to 90 per cent of the strength of the plates for thick stock, and over 95 per cent of the strength for thin stock. The various methods in use for welding the seams in tanks are shown in Fig. 22, those welded in two places being best for high pressure. These may be compared with the usual boiler riveted joints in Fig. 137. Since the strain on the longitudinal seams is

double that on the circumferential seams, it is customary to lap-weld the side seams for strength. When the tank or boiler is intended for use under high pressures, it is better to lap all seams. A butt strap is usually added to the side seams and welded at both sides and the center, as indicated in the next to the last detail of Fig. 22. The method of welding the head depends upon its shape, the convex head, flanged to slip inside the shell, being the most common. The welded seams are indicated in the figure.

Boiler makers have been slower to take up electric welding than have the tank makers, because greater restrictions have been

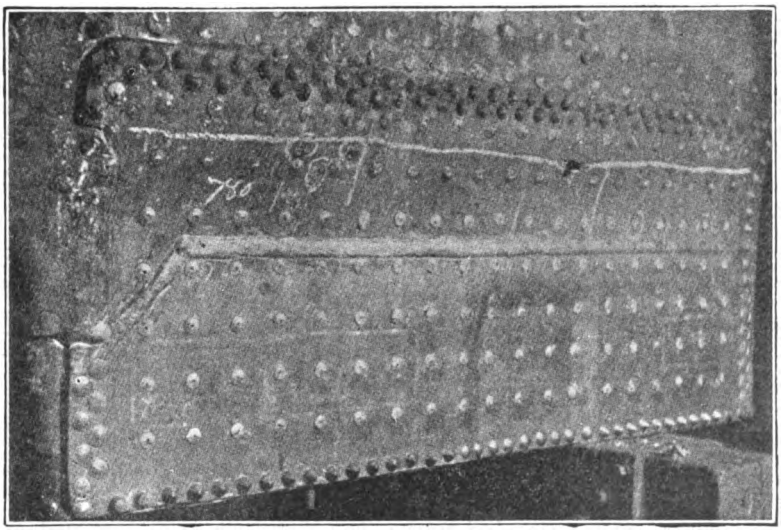


Fig. 23. Boiler Side Sheet Welded by Electric Welding Apparatus
Courtesy of "The Boilermaker"

put upon them by the insurance companies. But there is now a strong tendency among them to use electric-arc welding to an increasing degree, and boards of inspectors and other official bodies are more liberal each year. In the shipping trades electric-arc welding was first used only for minor repairs on boilers not subject to tension, then it was allowed for calking flues and seams, and now it is used for constructing certain parts of new boilers. Locomotive boiler makers were also slow to adopt arc welding, but now use it very extensively. House-heating boilers have been made with all seams welded. In the tank-building industry the

use of arc welding has superseded riveting in many cases for all but the heaviest stock, and some of the largest oil tanks have been welded throughout. Tanks to withstand pressures of 3600 pounds per square inch have been welded, and steel tube structures have been welded and subjected to pressures of 5000 pounds without fracture. Welding along the edges of the plates that have been riveted, instead of calking with a hammer in the usual manner, Fig. 138, ties the plates together, strengthens and tightens them, and the job never has to be gone over again. It will be evident from an examination of Figs. 23 and 24 that arc welding is far superior to riveted patches for repairing, and that some jobs which could not be done by the old method are easy by the new.

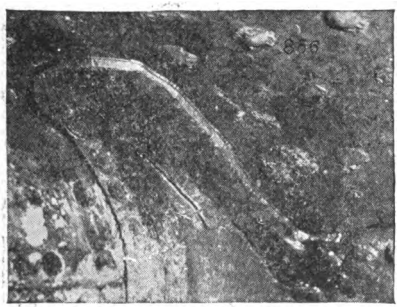


Fig. 24. Weld in Locomotive Fire Box
Courtesy of C. & C. Electric and Manufacturing Company

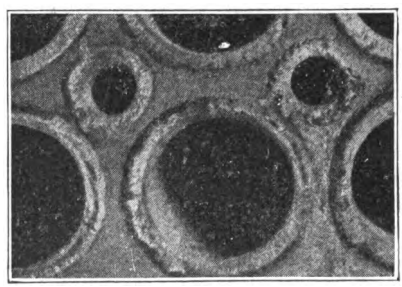


Fig. 25. Electrically Welded Boiler Tubes
Courtesy of "Railway Master Mechanic"

If the plates are badly corroded they may be restored to the original thickness by laying on a new surface with the metallic electrode; and leaking rivets or flues may be tightened by welding around the heads and fusing them to the plates. In the steel-barrel industry the electric-arc welding process has worked a revolution, and seams properly welded will hold gasoline and other volatile fluids and are not attacked by acids that do not attack the rest of the metal. Galvanizing is done after the seams are welded instead of before the barrel or drum is formed. The strength of the seam is as great as when made by any other process, and is much cheaper than when riveted and brazed. Heads of barrels may also be welded in by this process.

Welding Boiler Flues. One of the most important applications of metallic-electrode arc welding is to the welding of flues

into locomotive, marine and stationary boilers, Fig. 25. The flue end is expanded and beaded in the usual manner and then the edge of the bead or flange is welded all around so as to attach it to the sheet. A one-eighth inch wire and about 90 amperes should be suitable for this operation. The copper ferrule and prossering operation may be omitted when the flues are welded in. This makes tubes and sheet into one piece and eliminates leaking entirely, the life of the weld being that of the tube itself. The law demands new flues every three years, so the durability for locomotives cannot be estimated, but it is known that the life of

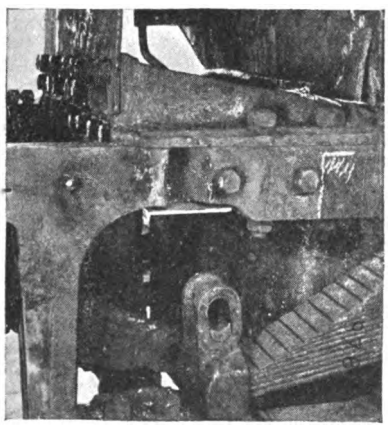


Fig. 26. Fractured Locomotive Side Frame Cutout with Graphite Electrode and Ready for Welding
Courtesy of C. & C. Electric and Manufacturing Company

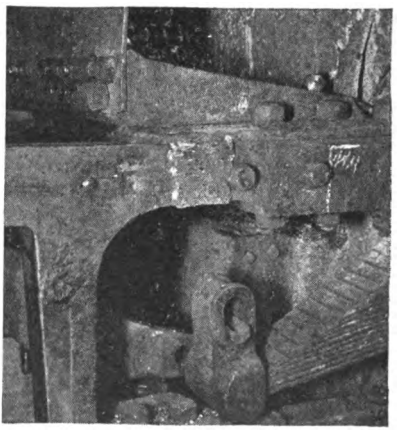


Fig. 27. Frame Welded with Metallic Electrode
Courtesy of C. & C. Electric and Manufacturing Company

welds in the flues of stationary boilers and in locomotive fireboxes isa s long as that of the sheets.

There are several thousand locomotives with welded boilers in use in this country today, most of them with the flues welded in. Broken mud rings may easily be welded without removing by cutting out a piece of the sheet opposite the break, welding the ring and then welding the piece of sheet back into place. The main frames of locomotives may be welded where broken, by using the metallic electrode. The frame must be beveled clear through at the break, to get room in which to work. A piece of cast iron should be placed below the opening to provide a base to

start on, Fig. 26. The metal is filled in by starting at the rear lower end and working upward from side to side. Layer after layer is laid on in this manner until the space is filled. A reinforcement should be placed on the outside surfaces to give the joint as much strength as the original metal, Fig. 27, and then smoothed slightly for looks. Similarly worn driving wheels may be built up, broken pilots and draw heads mended, valve and brake gear repaired, worn journals on axles built up to original

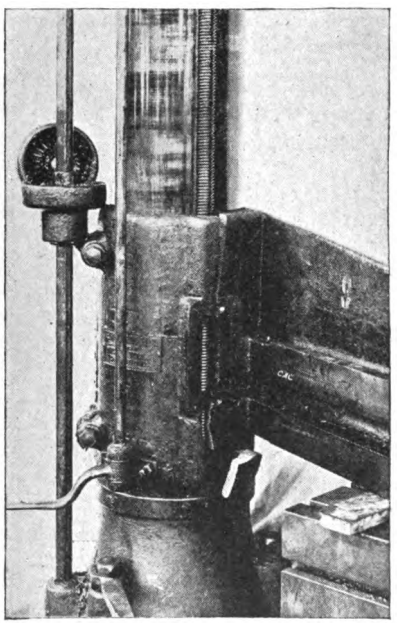


Fig. 28. Broken Housing of Radial Drill
Courtesy of C. & C. Electric and Manufacturing Company

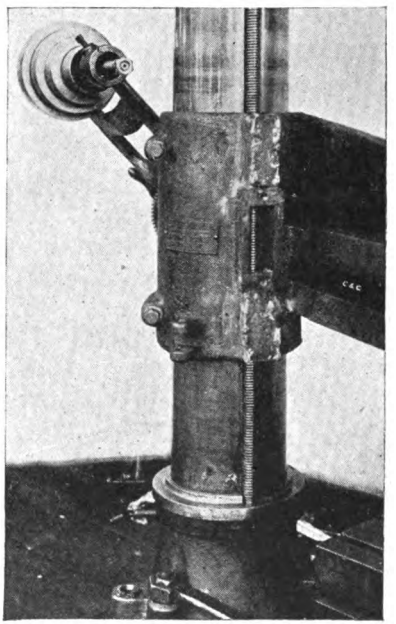


Fig. 29. Radial Drill Housing Welded with Graphite Electrode
Courtesy of C. & C. Electric and Manufacturing Company

size, broken truck frames and transoms mended and many other jobs done to better advantage by this than by any other process. Freight and passenger cars are now built by this process.

Welding Machine Parts. The use of the electric arc for welding machine parts, new and broken, Figs. 28 and 29, effects great savings. It saves the cost of new parts and prevents the loss of time incident to getting and installing them. In cases of breakage, Fig. 30, this method is employed to advantage; and it

TABLE II

Chemical Analysis of Iron and Steel Before and After Welding

Element	Sample No. 1, Iron		Sample No. 2, Steel	
	Per Cent Before	Per Cent After	Per Cent Before	Per Cent After
Silicon	0.000	0.003	0.04	0.00
Carbon	0.05	Trace	0.48	0.25
Sulphur	0.025	0.020	0.04	0.04
Phosphorus	0.068	0.043	0.08	0.07
Manganese	0.64	0.27	0.50	0.25
Iron (by difference)	99.108	99.664	98.86	99.39
Total percentage	100.000	100.000	100.00	100.00

makes possible in new work a joint much cheaper than a mechanical joint. Radical changes in design and details of construction are made possible by the use of this system in machine building, and the fact that the parts can be so joined as to be literally one piece opens up great possibilities. For work on cast iron the graphite electrode is used and a cast-iron melt bar is fused into place with the article in a horizontal position. Cast-steel parts requiring a moderate amount of welding may be done with the metallic electrode, but large welds can usually be done to better advantage with the graphite electrode, a wrought-steel melt bar or pieces of steel plate scrap being used to fill in with. Cast iron or steel can be welded soft enough to machine readily, by proper treatment, and the quality equal to the rest of the article.

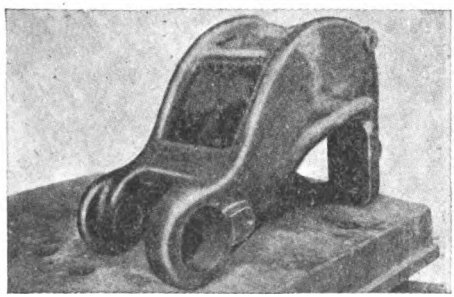


Fig. 30. Punch Press Frame Welded with Graphite Electrode
Courtesy of C. & C. Electric and Manufacturing Company

Preheating Parts for Welding. When welding cast iron pieces it is usually better to preheat them to a dull red color in a charcoal fire or gas forge to prevent unequal expansion and the consequent liability to cracking on cooling. Such heating is especially necessary to insure a weld soft enough to machine after it has cooled. In welding pulley wheel spokes it is best to heat the

spokes or rims at each side of the break; expansion of the metal due to heat opens the crack, and after the filling material is put

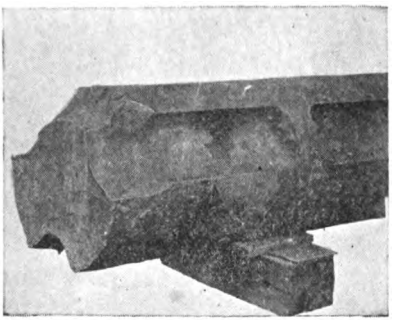


Fig. 31. Broken Rolling Mill Steel Wabbler
Courtesy of C. & C. Electric and Manufacturing Company

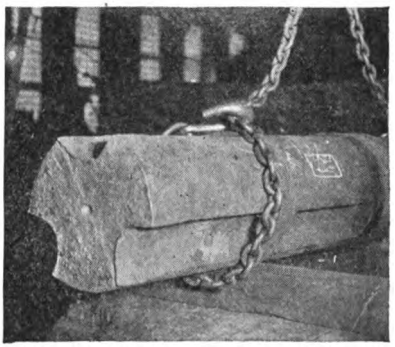


Fig. 32. Wabbler Welded with Graphite Electrode
Courtesy of C. & C. Electric and Manufacturing Company

in the weld draws together as it cools without cracking. For cylindrical bodies it is best to heat the entire piece, and large masses of steel casting should also be heated. Steel forgings and sheets may be welded cold by using the metallic electrode, although large forgings like Figs. 31 and 32 should be welded with the graphite or carbon arc on account of the saving in time. Heavy crank shafts, Figs. 33 and 34, may also be welded without heating and with either metallic or carbon electrodes, according to size.

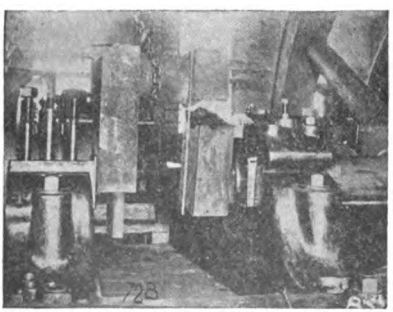


Fig. 33. Broken Steel-Forged Crank Shaft Ready for Welding
Courtesy of C. & C. Electric and Manufacturing Company

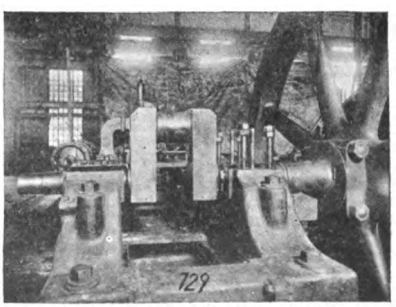


Fig. 34. Crank Shaft Welded with Graphite Electrode
Courtesy of C. & C. Electric and Manufacturing Company

From Table II, it will be seen that it is necessary to use filling material of the proper composition if the weld is to be the

same in composition as the original article. By merely using electrodes and melt bars with an excess of such elements as silicon, carbon, etc., the composition can be controlled. Unless the operator burns his metal by using too much current or applying it too long, there will be no appreciable difference in color between the weld and the rest of the piece.

When welding alloy steels, such as cutting tools, it is usually satisfactory to use Swedish iron on account of its tendency to

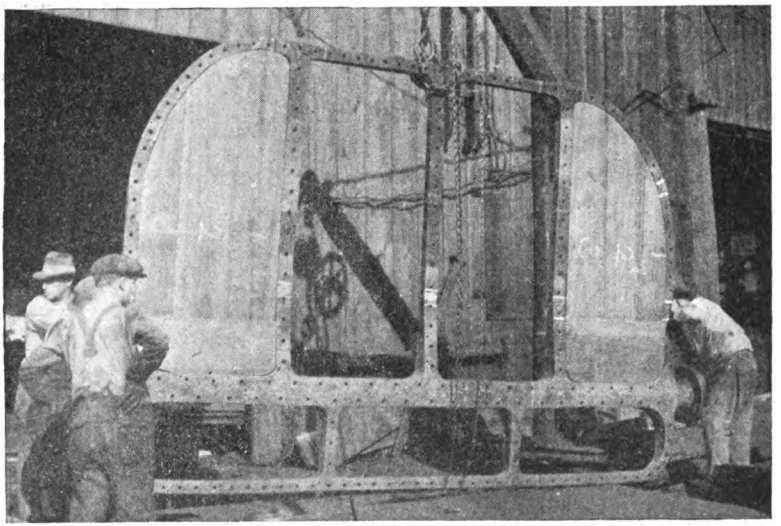


Fig. 35. Arc-Welded Cast Steel Rudder Frame

alloy with the steel, although some classes of work require electrodes or filling material of special alloys.

Shipbuilding and Marine Repairs. Marine repair shops and shipbuilding plants are now using large numbers of electric-arc welding outfits for all sorts of construction and repair work. Before the late war with Germany it was very hard to interest ship men in using arc welding for new work, and only to a comparatively limited degree would they use it in making repairs; but when the United States took over the interned German vessels and found that the machinery had been deliberately injured, it was by the use of arc welders that most of the repairing was done. Some of the work was also done with gas and some by the thermit process, but the electric-arc system deserves most of the

credit for getting the vessels into service so quickly. As a result, arc welding now is accepted for a great many operations that were formerly prohibited in shipbuilding.

Boiler cracks and leaks due to corrosion, broken propeller blades and crank shafts, stern frames and rudder frames, Fig. 35, anchors, deck plates, hull plates and framing, ventilators, hatch covers, bunkers and bulk heads have all been successfully welded with the electric arc, and the work is done better and cheaper than by any other method. Vessels having arc welders aboard are independent of repair shops and are seldom at the mercy of storms in case of accident. Most broken parts may be welded in place, thus the time and cost of dismantling and re-assembling may be saved. These equipments are installed on the docks of steamship companies for making repairs while vessels are transferring cargoes.

Recent Experiments. In the year 1915 a steel boat, built with electric-arc welded joints and hull and deck-plate seams, was put in service on Lake Erie. The over-all length of the boat is 42 feet, beam 11 feet, molded depth 6 feet 6 inches, draft 40 inches. The angle-iron frame or ribs have angles $1\frac{1}{2}'' \times 1\frac{1}{2}'' \times \frac{1}{4}''$, spaced 18″ apart. The keel is steel, made up of three pieces of $1'' \times 5''$ steel welded together, and to this the single-piece stern post is welded. The hull is of steel plates slightly under $\frac{3}{16}''$ thick and the deck is of No. 8 steel plate also. The edges of the plates were beveled to ensure welding to full depth. This hull has broken through ice four inches thick on the lake; it has been crushed between two large ore vessels and successfully straightened out; and there has not been a single leak in the welds.

A 275-ton, English-built, rivetless, welded barge was launched in June, 1918, for service across the English Channel. The hull is rectangular in cross section amidships, with only the bilge plates curved. The plating is $\frac{5}{16}''$ thick below and $\frac{1}{4}''$ thick above, and all the joints are lap-welded. Even when the plates are riveted, modern vessels frequently have the edges of the plates calked by arc-welding instead of by hammering. For work of this kind it has been found that 0.10 per cent carbon steel metallic electrodes are used, with about 150 amperes.

During the late war the Welding Committee of the Emergency Fleet Corporation conducted extensive experiments to determine

TABLE III

Strength of Butt-Welded Joints

Plate Thickness Inches	Elastic Limit Lbs. Per Sq. In.	Tensile Strength Lbs. Per Sq. In.	Elongation % in 8 In.	Per Cent Efficiency
$\frac{1}{4}$	40930	54650	4.5	97.6
$\frac{3}{8}$	44930	53020	5.75	94.7
$\frac{1}{2}$	40160	51280	4.75	91.6

the best of welding processes, and they recommended the greatly extended use of electric-arc welding, and the adoption of the other methods for specific operations. That Committee has since become the American Welding Society and very extensive developments are being announced by them.

Strength of the Weld. The strength of the weld can be made the equal of the article welded by reinforcing, or it can be made very nearly the equal by using filling material of high strength and welding flush with the surface of the piece, Fig. 36. This is especially true of steel plates. Some tests made for the author on steel plates of various thicknesses (with a nominal strength of 56,000 lbs. per square inch) showed the results given in Table III.

The elongation in the filling material was less than in the original material, of course, because the casting was steel, but the ductility can be improved by hammering after welding, and this is frequently done when welding heavy sections.

Comparative Test. In order to test the relative strengths of riveted, electric-arc-welded, and acetylene-welded joints, a set of steel samples were made up and tested by pulling, each piece

TABLE IV

Relative Strength of Joints

Samples and Preparation	Breaking Strain Pounds	Length After Breaking Inches	Per Cent Efficiency
Original piece of plate	58,600	8.80	97.66
Lap joint, arc welded	54,800	8.94	91.33
Lap joint, riveted and welded	54,200	9.22	90.33
Butt joint, arc welded	47,800	8.28	79.66
Butt joint, acetylene welded	36,800	8.23	61.33
Lap joint, riveted only	35,000	...	58.33

TABLE V

Relative Strength of Original and Welded Plate

	Size of Sample Inches	Breaking Strain Pounds	Per Cent Elongation in 4 Inches	Per Cent Reduction of Area
Welded piece.....	.125×1.48	42,702	10.93	5.23
Original piece.....	.125×1.48	48,290	32.03	29.63

being $\frac{3}{8}$ inches by $2\frac{13}{32}$ inches in cross section and 8 inches long in the straight portion, Table IV.

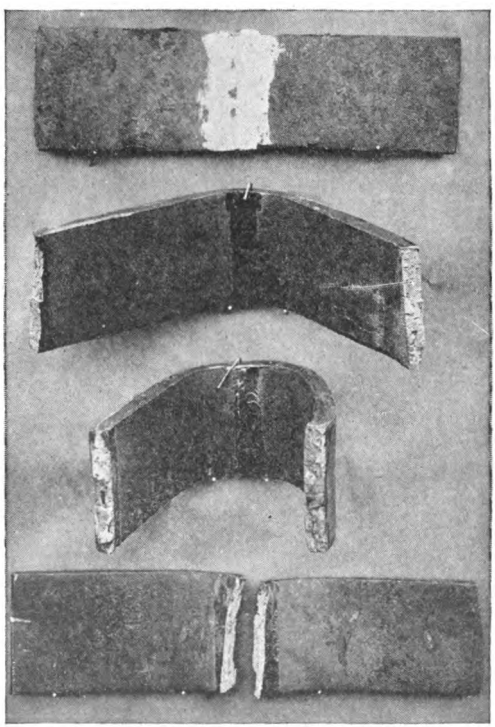


Fig. 36. Test Plates Showing Binding Strength of Electric Welds

Courtesy of C. & C. Electric and Manufacturing Company

Some tests recently made in England are shown in Table V. Strength of welded piece was 88.43 per cent of original plate.

Figure 36 illustrates four steps in a bending test on a plate that was "butt-welded," or welded end to end, with metallic elec-

trodes. First is shown the plate before bending; next the plate bent at right angle; third the plate bent until the sides are parallel, and fourth the plate broken through the weld after it was straightened out again. This plate was $\frac{1}{2}$ inch thick by 3 inches wide and of boiler-plate steel. In another test with steel ship plates $\frac{3}{4}$ inch thick and 8 inches square, butt-welded in the same way, the plates were first bent to nearly a right angle, then bent back to the same angle in the opposite direction; then back again as far in the first position before cracking, and finally straightened out flat before coming entirely apart.

The cylinder shown in Fig. 37 was made of two short pieces of 5-inch superheater flues from an old boiler, welded end to end with $\frac{3}{4}$ inch flat heads, and with metallic electrodes. Other high-

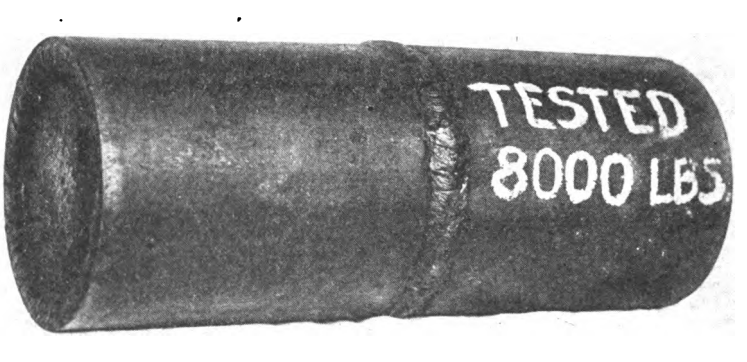


Fig. 37. Arc-Welded $\frac{1}{16}$-Inch Steel Cylinder, Five Inches in Diameter

pressure cylinders of large size, made under the direction of the writer, operate successfully and regularly at pressures up to 1,000 pounds per square inch.

The strength of any weld is affected by its structure and composition and by the presence of blow holes or gas holes and various impurities.

Structure. The crystalline structure is finer when the welding is done on a cool article, but becomes coarser as temperature increases, and, in consequence, weaker.

Composition. The composition of the weld is very important and may be varied through a wide range by adding various other metals to the iron of the electrodes. Non-ferrous metals, such as

TABLE VI

Time and Cost of Welding

Article Welded	Time	Cost
Steel casting, shrinkage crack 6″ long by 1″ deep	8 min.	$00.04
Steel casting, riser 4″ by 4″ cut off	4 min.	.05
Forged steel locomotive frame, broken in 2 places	20 hrs.	18.28
12″ crack in back sheet of locomotive boiler	9 hrs.	5.47
Building up worn driving wheel instead of turning down	2 hrs.	.72
Welding 67 cracks in old fire box (saving over $1000)	2 wks.	52.60
Cast-steel tender frame, broken in 3 places	27 hrs.	19.00
Steel shaft, 2″ diameter, broken, welded ready to finish	1 hr.	.60
Broken railway type motor case, cast steel, welded	3 hrs.	1.95
Enlarged holes in brake levers, steel bars	4 min.	.05
Building up 2″ armature shafts, worn in journals	3 hrs.	1.80
Air brake piston rods, broken, welded ready to finish	30 min.	.35
Leaking axle boxes, cracks, welded in position	15 min.	.15

copper and aluminum, should not be used in electrodes for welding articles of steel or iron, and fluxes are generally of no value to a good operator.

Blow Holes and Gas Holes. Holes in the body of the weld cause brittleness. They are due partly to gas-forming elements in the electrode, but more to carbon in the metal worked upon.

Impurities. The ductility of the weld is considerably affected by impurities. Although properly coated electrodes make a more ductile weld than bare wire, some coated-wire electrodes deposit slag, which weakens the weld more than anything else. Nitrogen in the weld, which is probably due to the formation and decomposition of oxygen-nitrogen compounds under the action of the arc, makes the weld brittle; but this element cannot well be eliminated.

Cost of the Various Operations. The cost of arc welding will vary according to the nature of the work, the skill of the operator, and the cost of labor and current, but it is much less than for similar work done by any other process. It ranges from about three-fourths down to one-tenth that of the cost of acetylene welding, for various jobs, and the time required is much less. With the electric arc it is not necessary to keep a large portion of the work heated in order to prevent the chilling of the filling material, because the work forms the hottest (positive) terminal of the arc and a sufficient volume of heat is generated at the point which is being worked upon to insure perfect fusion.

TABLE VII

Cost of Welding in Railroad Shops

Description of Items	Cost by Other Methods	Cost by Arc Welding	Saving	No. of Engines
Pedestals	$645.00	$45.24	$599.76	5
Tank frames	9.03	1.36	7.67	1
Shop tools	34.36	3.40	30.96	4
Piston rods	78.64	16.37	62.27	10
Sharp flanged drivers	165.40	20.28	145.12	3
Truck side	194.00	10.20	183.80	4
Building up driving axles	121.50	4.90	116.60	1
Steel car underframing	11.34	1.71	9.63	1
Building up worn car axles	315.00	25.24	289.76	..
Bushing staybolt holes	294.96	73.74	221.22	26
Welding flues	2607.65	521.53	2086.12	102
Frames	931.00	133.28	797.72	11
Cracks in fire boxes	2431.27	297.17	2134.10	92
Totals	$7839.15	$1154.42	$6684.73	..

Cost Data in Steam Railroad Shops. The figures in Table VI show the cost of several actual jobs done with arc welders, the labor being paid at the rate of 30 cents an hour and the current costing 2 cents a kilowatt hour, and the filling material 8 cents a pound. The labor cost is about half the total.

On account of the necessity for keeping the rolling stock and motive power in operation as much of the time as possible, the steam railroads have probably benefited more through the adoption of arc welders than any other industry. The time saved through avoiding dismantling when making repairs with arc welders will usually pay for a welding and cutting equipment in six months or less. The records kept by the Chicago, Rock Island and Pacific Railroad show the great value of an arc welder as compared with the other methods of making repairs. The preceding table gives some of the data.

Comparison with Old Methods. The figures in Table VI will give a fair idea of the class of work and the costs of welding in steam railroad shops and car shops, and those in Tables VII and VIII will show the savings effected through the use of arc welding instead of making repairs by the old methods, of whatever kind.

Experiments in the U. S. Navy Yards show that the speed of welding half-inch ship plates is somewhat more than 3 feet of seam an hour for each man, and that slightly more than one-half

TABLE VIII

Relative Costs of Repairs

Article Welded	Welding	Old Cost	Saving
Engine main frames, both broken	$11.80	$56.20	$44.40
Driving wheel built up $\frac{3}{16}$" on tread	.72	8.00	7.28
General repairs on fire box side sheets	66.51	342.62	276.11
Filling worn knuckle joint bushing hole	.75	7.50	6.75
Welding 7 cracks in locomotive cylinder	22.35	367.15	344.50
Broken mud ring on locomotive boiler	32.07	118.06	85.99

pound of metallic electrode (of which about 15 per cent will be lost as waste ends) is used for each foot of seam welded. It requires about 30 pounds of electrode per ton of structural steel welded, and takes about $2\frac{1}{2}$ kilowatt-hours of power for each pound of metal deposited. The labor runs about $15.00 for each ton of material welded. This gives a net average of somewhat less than $22.00 for welding one ton of ship structure. A twelve-foot cubical tank of half-inch plate recently made by the General Electric Company contains 16,000 pounds of steel plate and 300 pounds of electrode metal. There were 500 feet of seam welded in 165 man-hours. Including labor, which cost approximately $150, the total cost was about $1000.

Street Railway Repairs. Repairs to electric railway apparatus are also important in order to keep the rolling stock in useful service. The figures in Table IX, which give average costs for performing typical repair jobs in street-car shops, are based upon the relation between the cost of electric welding as opposed to replacement since the latter is usually the alternative.

TABLE IX

Street Railway Repairs

Article Welded	Welding	New Part	Saving
Armature shaft, repaired in place	$1.70	$ 4.72	$ 3.02
Armature shaft, large, repaired in place	1.97	15.13	13.16
Railway motor axle cap, large	.22	3.51	3.29
Railway motor armature bearing cap	.27	6.07	5.80
Railway motor gear case, top half	.48	7.30	6.82
Truck side frame, Brill 27-G	.72	44.40	43.68
Truck side frame, Peckham 14-B	.90	46.98	46.08
Brake head, building up worn socket	.06	1.15	1.09
Motor frame, G. E. 90, railway type motor	2.88	16.80	13.92

One of the electric-railway companies claimed that it repaired about 1600 articles a year. If these articles had been replaced by new pieces, the cost would have been nearly $15,000. In addition to the money saving, there was a large saving of time, as the repairs were quickly made and the rolling stock was out of service little of the time. The use of electric-arc welding apparatus is not confined to the railway field. Equally interesting figures could be given as applying to work done in foundries, machine shops, boiler and tank shops, garages, and other places. These few will serve, however, to show the possible savings through using the arc for repair work in general.

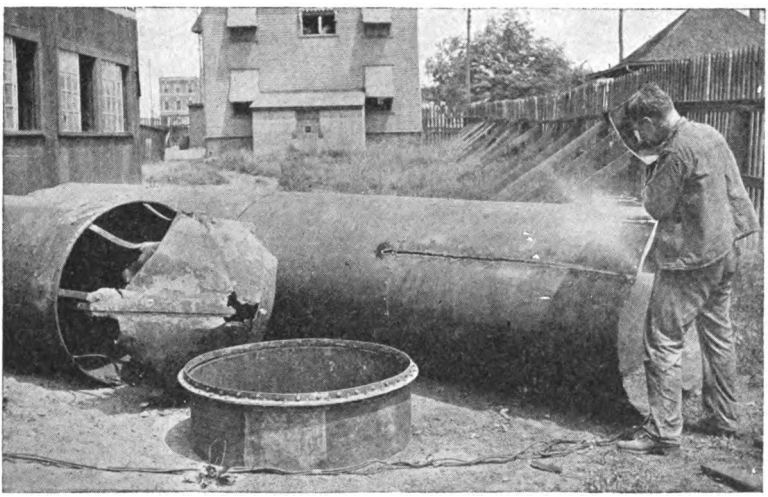


Fig. 38. Cutting Scrap with a Carbon Electrode
Courtesy of C. & C. Electric and Manufacturing Company

ELECTRIC ARC CUTTING

Advantages of the Method. Cutting with the electric arc can be done very rapidly and economically. It is practiced a great deal in foundries, scrap yards, Fig. 38, and other places. The slot cut is not so narrow as that cut by a gas flame, but the metal is good after it is fused out and may be used again. Aside from the slight oxidation that occurs when iron or steel is cut, there is no injurious change in the metals. Some of the more volatile elements may be reduced by the high temperature, but the mass being cut will remain unchanged. In the case of the

gas processes, on the contrary, there is a chemical reaction which often makes the metal unfit for other use.

When fabricating ships, tanks, boilers and other articles of steel plates, it is frequently desirable to cut openings in them after fabricating instead of beforehand. This is especially true in the case of adding manholes or placing windows or hatchways in vessels, or putting extra manholes in tanks. Such work can readily be done by using the carbon arc to cut through the sheets and then trimming the edges of the holes with an air chisel for smoothness. Sometimes it is found that an opening is in the wrong place, so it is easy to weld in a plate with the metallic electrode and cut a new opening with the arc. Structural steel pieces may also be cut to length with the arc and the ends smoothed up later, if necessary, although for many purposes rough ends are usually no disadvantage. Removing defective pieces of rails or worn crossing castings from car tracks can best be done with the electric arc, and many other applications will suggest themselves to experienced operators.

Current Requirements. Cutting is done with the graphite electrode and requires from 100 amperes on sheet metal up to several hundred on heavy castings and forgings. The maximum current which it is practical or necessary to use should never exceed 1000 amperes and the usual cutting operations take from 400 to 600 amperes. Direct current is used, the same as for welding, and almost any source of supply will give satisfactory results if proper means are provided for controlling the current. However, apparatus which has been specially developed for the service is much better and more reliable than makeshift devices and, as experience shows that the cost of cutting is just as important as the cost of welding, dead resistances should not be used.

Rate of Cutting. The rate of cutting has been found to be very close to one square inch of cross section per minute for each 100 amperes used in the arc. This rate will be increased slightly for sheet-metal work but applies very closely for heavy sections. On the basis given, a section 4 inches by 6 inches (24 square inches) can be cut in 4 minutes with 600 amperes. A steel plate 1 inch thick and 1 foot wide (12 square inches) can be cut in 2 minutes with from 400 to 450 amperes. Sheets of copper, alumi-

num, and other metals can be cut at about the same rates as steel. When cutting it is necessary to make the slot wide enough to allow the arc to reach to the bottom of the cut instead of jumping to the sides, and the piece should be placed so that the molten metal can run out of the slot. Work should begin at the top of the piece, and progress downwards and across until the entire cross section has been cut through.

ELECTRIC BUTT AND SPOT WELDING

Characteristics and Development of the Process. The use of the electric current to heat metals to the welding point, by passing

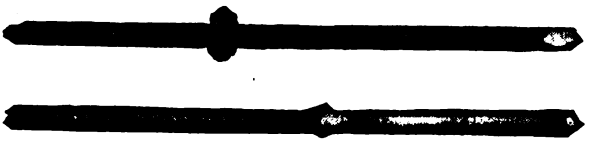


Fig. 39. Welded Bars Showing Upset
Courtesy of Toledo Electric Welder Company

the current through the joint until the metal becomes plastic and then applying sufficient pressure to cause the pieces to adhere, was first proposed by Elihu Thomson in 1877; and the present-day process of "resistance welding," in its various forms, is the

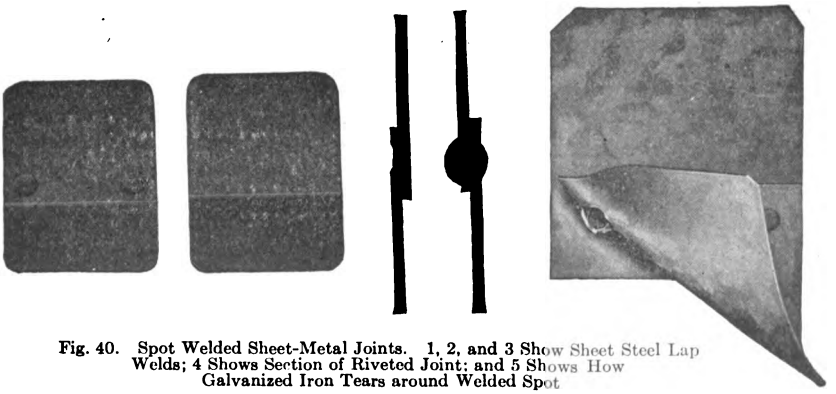


Fig. 40. Spot Welded Sheet-Metal Joints. 1, 2, and 3 Show Sheet Steel Lap Welds; 4 Shows Section of Riveted Joint; and 5 Shows How Galvanized Iron Tears around Welded Spot

result of his work. The process is based upon the phenomenon that a poor conductor of electric current will heat if current is forced through it, or that a good conductor also will heat if enough current is passed through it, and that the heating effect will be greater if alternating current is used than if direct current

is used. Since an imperfect joint between two pieces of metal is a poor conductor and offers resistance to the passage of current, it will naturally heat and finally cause the metal to soften sufficiently to weld. In practice the operation is very rapid because comparatively large amounts of current are used and heavy pressures are applied.

Originally this process was used to weld bars and strips together, end to end, Fig. 39, performing the operation known as "butt welding," and this is today one of the principal uses of the system. Later, a modification of the system was made in order that pieces of sheet steel could be welded; this resulted in the development of the operation known as "spot welding," by means of which lapped joints can be made, Fig. 40, particularly of thin

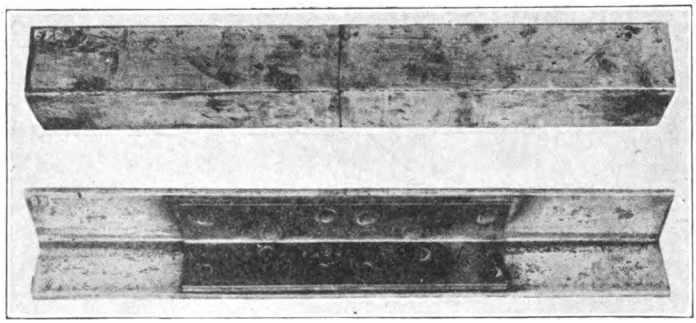


Fig. 41. Single-Strap Butt Joint, Spot Welded
Courtesy of Toledo Electric Welder Company

material. Heavy plates cannot be spot welded so readily as thin ones, and they are usually joined by a combination of butt and lap weld; that is, the plates are brought together edge to edge and a strip of plate is laid on over the joint and welded, Fig. 41. Special machines have been developed for numerous operations and for a wide range of articles, and the work done with them is of the highest class. Practically every kind of metal can be welded by this process and many different kinds may be joined together, as shown in Table X. The great advantage of this process lies in the amount of work which can be done in a short time, but it is limited almost exclusively to the production of new articles instead of being also good for repair work like the arc system.

TABLE X

Metals, Alloys, and Combinations of Different Metals Actually Welded by the Thomson Process

Metals					
Wrought Iron	Wrought Copper	Tin	Cobalt	Aluminum	Gold (pure)
Cast Iron	Lead	Zinc	Nickel	Silver	Manganese
		Antimony	Bismuth	Platinum	

Alloys					
Various Tool Steel	Mushet Steel	Wrought Brass	Fuse Metal	Aluminum and Iron	Silicon Bronze
Various Mild Steel	Stub Steel	Gun Metal	Type Metal	Aluminum Brass	Coin Silver
Cast Steel	Crescent Steel	Brass Composition	Solder	Aluminum Bronze	Gold Alloy
Chrome Steel	Bessemer Steel	Nickel Steel	German Silver	Phosphor Bronze	

Combinations					
Copper to Brass	Brass to Wrought Iron	Brass to Tin	Wrought Iron to Tool Steel	Wrought Iron to Mushet Steel	Wrought Iron to Nickel
Copper to German Silver	Tin to Zinc	Brass to Mild Steel	Gold to German Silver	Wrought Iron to Stub Steel	Tin to Lead
Copper to Gold	Tin to Brass	Wrought Iron to Cast Steel	Gold to Silver	Wrought Iron to Crescent Steel	Mild Steel to Tool Steel
Copper to Silver	Brass to German Silver	Wrought Iron to Mild Steel	Gold to Platinum	Wrought Iron to Cast Brass	Nickel Steel to Machine Steel
	Brass to Platinum	Steel to Platinum	Silver to Platinum	Wrought Iron to German Silver	

From a study of Table X it will be seen that practically all the commercial combinations of metals can be made with butt- or spot-welding apparatus and, it may be added, there is no other system in use today that will do welding on as wide a range of metals, alloys, or combinations. This system operates on a very low voltage—about 3 volts—and the important factor, as with arc welding, is the amount of current.

For a great many years butt welding was used only for articles of iron and steel, but now the copper bars for the rotors of induction motors and other electrical apparatus are welded, and most other metals are also butt-welded. Spot welding was

also limited in its application until comparatively a few years ago, being used mostly for thin sheets; now such heavy articles as the framing for steel cars, ships, steel trusses for roofs and

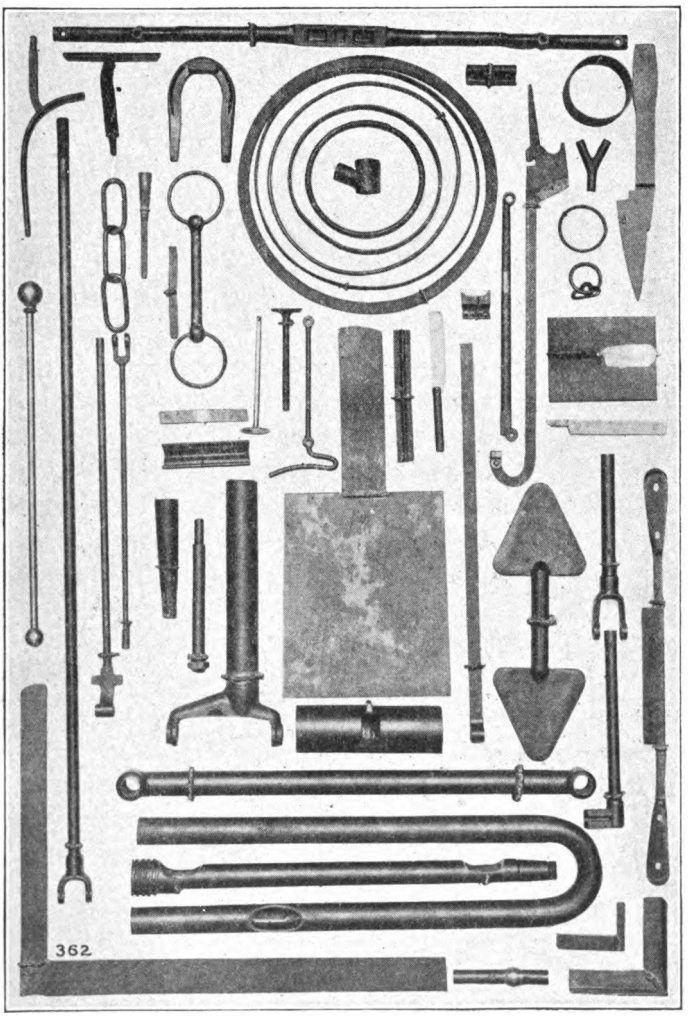


Fig. 42. Samples of Butt Welding
Courtesy of Toledo Electric Welder Company

bridges, steel tank and ship plates, car bodies, automobile framing, etc., are successfully spot welded up to a thickness of one inch.

Figure 42 shows a collection of samples of butt-welded small

parts, indicating but a few of the many thousands of articles that may be butt-welded. Chains, rings, tire bands, automobile parts, carpenters' and masons' tools, special pipe fittings, wire fences, broilers and sifters of steel bars, bicycle parts and even small castings may be butt-welded.

Equipment Required. Butt or spot welding practically requires a separate machine for each class of work to be done. These

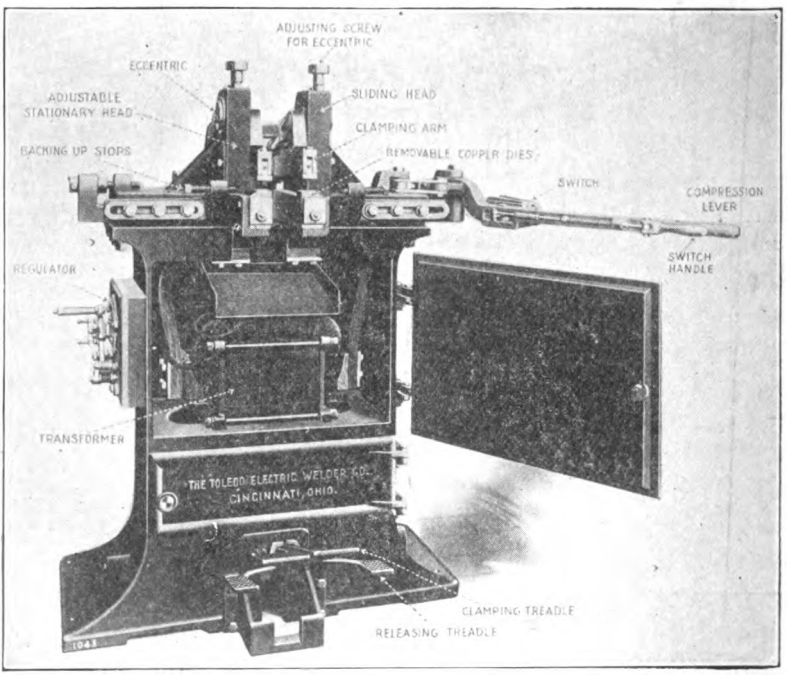


Fig. 43. Double Treadle Butt Welder
Courtesy of Toledo Electric Welder Company

machines consist of a main frame, Figs. 43 and 44, containing a transformer and some means for clamping the article to be welded, together with a device for applying the pressure required to force the parts together when heated. Unless the machine is designed for one special sort of articles, it is necessary to have a reactive coil to adjust the current to suit the work and a switch to control this coil. A main switch for connecting the welder to the power circuit is necessary, and the larger sizes of machines are water cooled.

The illustrations scattered through the text of this section show the more important types of machines, and the pipes for carrying the cooling water to the copper contacts are clearly

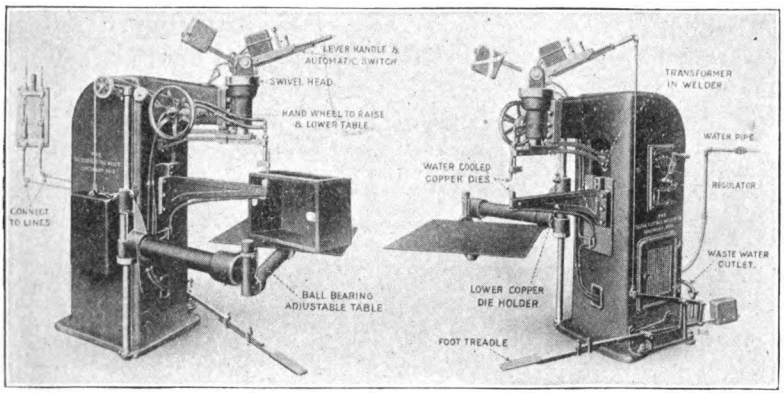


Fig. 44. Principal Parts of Spot Welder
Courtesy of Toledo Electric Welder Company

shown on most of them. These machines are built for welding pieces having cross sections as small as fine wires or seven or eight inches square, Fig. 43; the latter require 200 horsepower. With the proper transformer, butt-welding or spot-welding machines can be operated from any single-phase power circuit supplying current at a constant voltage, but direct current cannot be used.

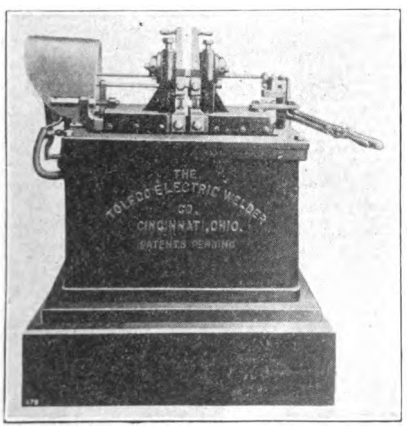


Fig. 45. Toledo Small Butt Welder

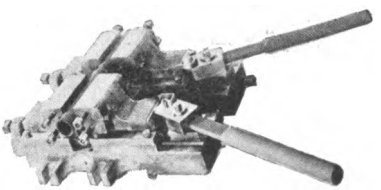


Fig. 46. Butt Welder Clamps for Pipes
Courtesy of Thomson Electric Welding Company

For spot welding large plates or structural-steel work there are special machines with long jaws or arms which reach across the material to the place to be welded. Currents of several

thousand amperes are required for welding cars and ships, and jobs on as many as three thicknesses of one-inch plate have been successfully spot-welded since the beginning of the World War. Tanks and boiler shells are also welded on special machines with long jaws, and an almost endless variety of small outfits have been developed for special applications of both butt and spot welding

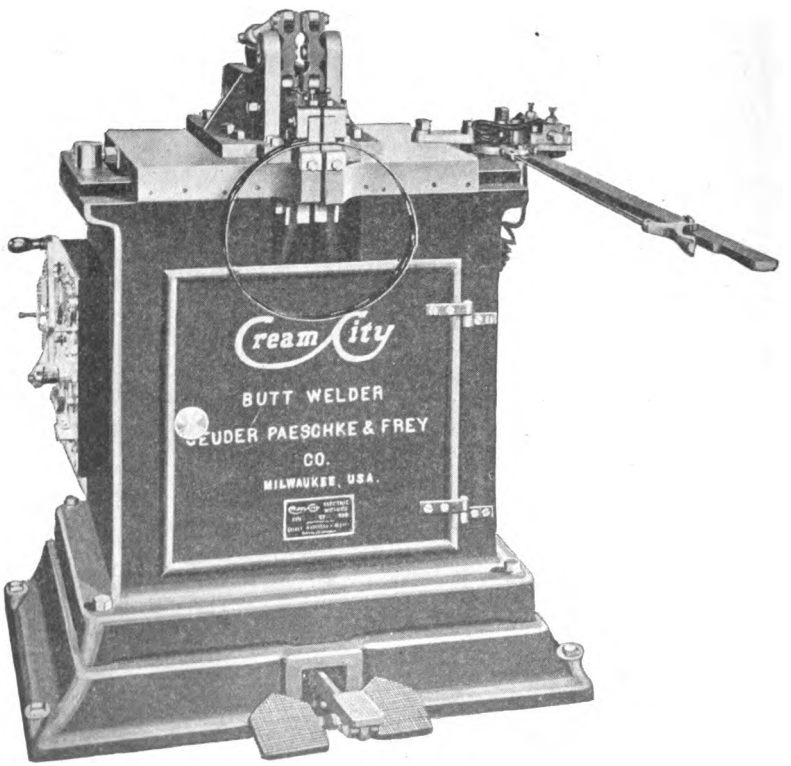


Fig. 47. Foot-Operated Butt Welder
Courtesy of Geuder, Paeschke, and Frey Company

and for continuous welding of seams. The development of machines of such large capacities has also resulted in the production of special transformers of very large capacity to handle the heavy single-phase currents, and has necessitated distributing the loads from the three-phase and two-phase generators in the power plants so as to prevent serious unbalancing of the demand. No special power plant changes are required for small equipments.

Butt welders are comparatively low machines, Fig. 45, with clamps for the work on top, generally in the form of jaws, with a lever for operating each pair, Fig. 46, and another lever or a hydraulic cylinder to bring the pieces together and to apply the required pressure to them when they are properly heated. The

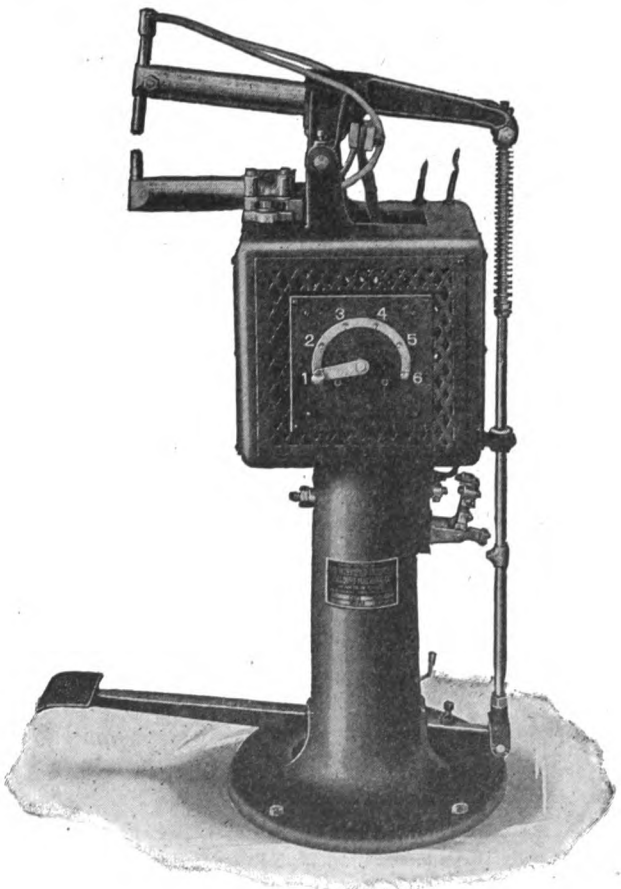


Fig. 48. Foot-Operated Spot Welder for Sheet Metal
Courtesy of Winfield Electric Welding Machine Company

current is carried into the pieces through the jaws and is usually turned on automatically after the parts are clamped into position. Foot levers are provided on some forms of machines, Fig. 47, for clamping in order to leave the workman's hands free to handle the work. Spot welders, Figs. 48 and 49, are usually higher but

smaller and have a pair of arms, Fig. 50, extending to one side for carrying the two welding tips or contacts; the pieces are laid together and placed on the lower contact and the upper one is forced down against it. The current is automatically switched on, when the contacts close, and the pressure is applied by a

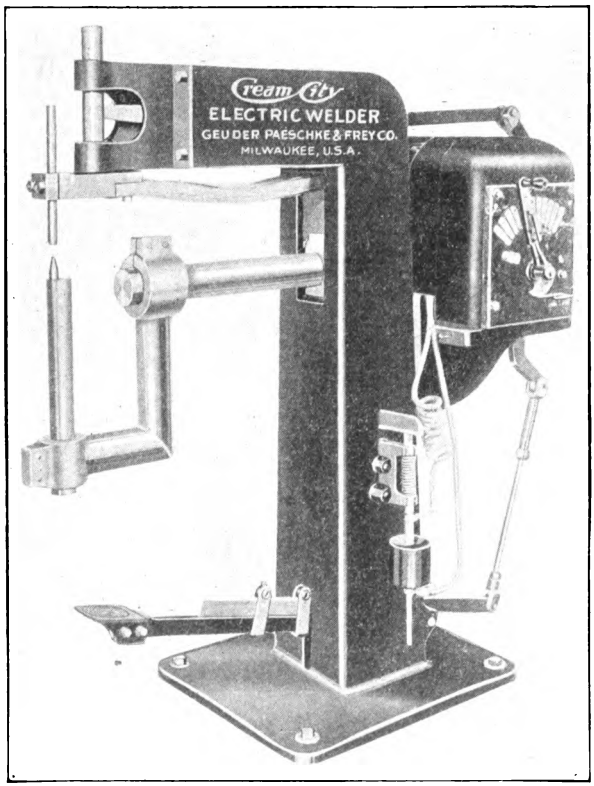


Fig. 49. Spot Welder Showing Simple Construction
Courtesy of Geuder, Paeschke, and Frey Company

hand or foot lever. Special machines are also made for rail welding, etc., Figs. 58 and 61.

Source of Power. *A. C. City Circuits with Transformer.* The source of power for butt welders and spot welders should have the same general characteristics as for arc welding; that is, they should deliver the current at constant voltage regardless of load. In most places current can be purchased from a public-service

corporation, and a transformer, to give current at the desired voltage, will be furnished to power users. City distribution circuits are usually operated at 2200 volts in order to reduce the amount of copper required for the lines, and, since alternating current is required for butt- and spot-welding, it is easy to get current at proper voltage by using a transformer. Most welders are provided with their own transformers, wound to operate on a 220-volt circuit, (although they can be made for use on any voltage up to 550 if necessary). Consequently, the line transformer should have a 220-volt secondary winding. The welding transformer will step the voltage down to the proper amount for welding and at the same time increase the current to the required amount. When it is necessary for the user of a welder to furnish his own power, it is best to use a motor-generator set, as such a machine will give better regulation than a rotary converter or a synchronous transformer.

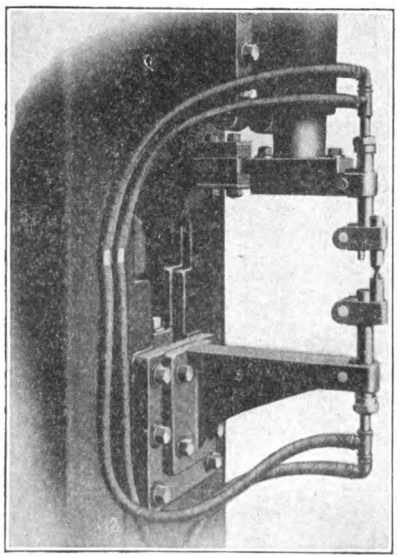


Fig. 50. Details of Spot Welder
Courtesy of Toledo Electric Welder Company

RESISTANCE WELDING OPERATIONS

Wide Applicability of the Method. The resistance method is the simplest of all methods of joining metals, and it is also the quickest and cheapest for such work as can be handled to good advantage by this process. It is limited almost exclusively to the production of new work, and, while it is especially good for articles of small size, it can be used to do such a quantity and variety of work that it is employed in hundreds of lines of production. The pieces are put into the machine, the current is passed through the parts to be joined until they are sufficiently heated, and then the pieces are squeezed together until they join, which is very quickly. At the proper welding temperature the metal is in a plastic state and the molecules or particles of the

metal amalgamate, or mix, so as to form one piece. If the pieces are of different metals, the result is an alloy of the two metals at the joint.

When the material is such that it is injured at high temperatures, as in the case of brass and some grades of tool steel, it should be heated quickly and pushed together hard enough to squeeze the burnt metal out of the weld and bring good metal into contact while plastic. Experience will soon show the correct heat for the best results with each metal; however, the makers of the various welding outfits are always ready to furnish information as to the proper current, time, temperature, etc., for any sort of work which may be done on their respective machines.

Sometimes efforts are made to do heavy work on small outfits, but this is dangerous and likely to result in burning out the machine. Small work may be done on a large machine, of course, but not economically. On the whole, it is best to get the machine suitable for the work to be done and use it for that and nothing else.

Reference has already been made to some of the recent developments and applications of butt and spot welders, such as in shipbuilding, steel-car work, etc.; and the very near future will undoubtedly see even greater strides made. On page 68 will be found a description of percussive welding, which is one of the modifications of the resistance systems. The use of butt and spot welders for heating pieces of metal, instead of placing them in furnaces, is another new application of the apparatus; with proper attachments metal parts may be heated and bent at practically one operation.

Butt Welding. Butt welding is applicable to welding metals of practically the same cross section. All the energy passing through the joint is effective because it is confined to a limited area of contact. A slight projection or fin will be raised at the joint, Fig. 39, owing to the flow of the soft metal, but this is easily removed.

Spot Welding. Spot welding, the operation of joining sheets by heating and softening the metal in spots only, Fig. 51, each about the size of a rivet, and applying pressure while the metal is plastic, causes a slight thinning of the metal at the weld, No. 3, Fig. 40. This is due to the pressure, but when the operation is properly done the joint should be as strong as the rest of the sheet.

Modifications of Butt and Spot Welding. Numerous modifications of the butt- and spot-welding processes have been developed for special shapes and sizes of pieces, such as lap welding, butt seam welding, tee welding, jump welding, cross welding, upsetting, annealing, and brazing. The last two, though not welding in the true sense, may be accomplished with the resistance-welding machine. Hardening and tempering also may be done with this apparatus, and rivet heads may be heated and pressed down where spot welds are not desired.

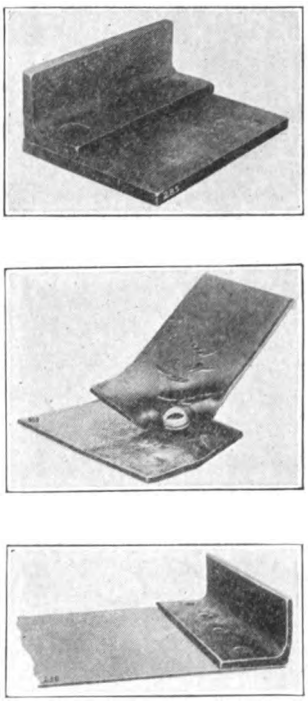


Fig. 51. Example of Spot-Welded Joints
Courtesy of Toledo Electric Welder Company

Lap Welding. Lap welding consists in making a joint by overlapping the edges of the sheets to be welded, heating the joint, and applying pressure by means of rolls which pass along the seam. This makes a continuous seam, instead of merely a series of spots, and gives a tighter and stronger joint than spot welding. It is used to a lesser degree than either of the other methods, but is coming into more general use for special purposes such as welding-in barrel heads, making grease cans, oil tanks, etc. Seam welding is a similar operation.

Butt Seam Welding. Butt seam welding is an operation similar to ordinary butt welding in one respect and like lap welding in another. It is used for making the seam in steel plate articles of moderate thicknesses, such as range boilers; it is done in a machine which brings the edges of the plates together and does the welding by pressure while hot, in the usual manner, Fig. 52. The special feature of the machine lies in the fact that the current is carried into the plates and across the seam by means of rolls each side of the joint. As the work progresses through the machine, the rolls keep the current always passing across the joint just ahead of where the pressure is applied.

Tee Welding. Tee welding is the process of making a weld in the shape of a "T" by welding one piece to the side of another.

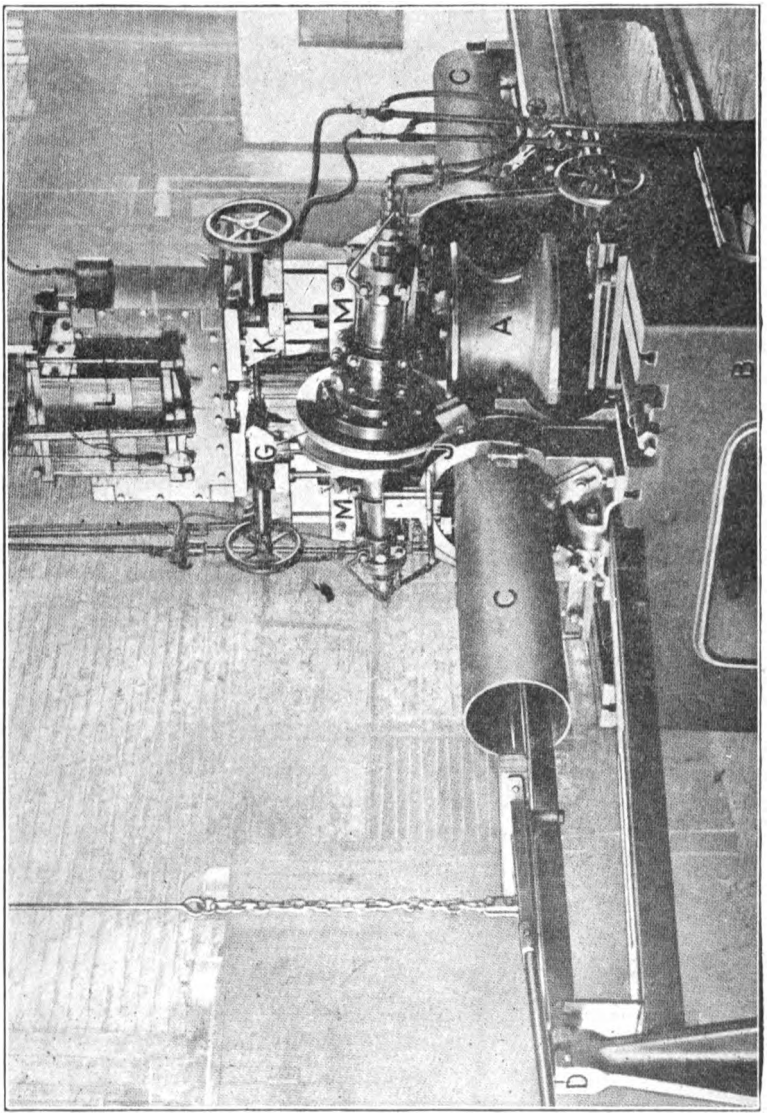


Fig. 52. Electric Welding Machine for Cylinders with One Cylinder in Position

The peculiar feature of this process is that the head of the tee must be heated first in order that the shank may not be burned before the parts are both soft enough to weld.

Jump Welding. Jump welding is similar to tee welding and is used on light stock which does not require preheating before welding. This process is also used for pipe work, when forming tees or welding branches into larger pipes, and the hole in the header or main pipe should be made before welding the branch.

Cross Welding. Cross welding is done when forming wires or bars into screens or when making any other article requiring the crossing of strips. The pieces are merely laid together and a welded joint formed at the crossing in either a butt-welding or spot-welding machine. The pieces will flatten at the joint, of course.

Upsetting. Upsetting is the operation of forming an enlarged section on a bar for the purpose of increasing its strength or reforming it to another shape. The bar is placed between the jaws of a butt welder, the current passed through the space to be upset, and pressure applied when the bar heats. The pressure will squeeze the metal up so that the bar will expand; it may be hammered into the desired shape while hot. This process must be distinguished from ordinary butt welding in which the joint swells and shows an "upset." Deliberate "upsetting" is usually carried much further. A "flash weld," a similar operation, is used on wide stock or on rectangular pieces and whenever the ends of the stock cannot be trimmed square. It consists in squeezing the metal so hard and rapidly while soft that it almost "squirts" apart. Feathery fins are formed around the joint, and these must be ground off. This weld is used for brass and copper, and an amount equal to the diameter or thickness of the material is taken up in the weld.

Electric Annealing. Electric annealing can be done with either a butt welder or spot welder. It consists in passing the current through the part to be annealed, heating it until soft, and allowing it to cool slowly. Hardened steel plates, springs, dies, tools, chilled rolls, etc., may be treated this way and may then be drilled or cut very readily. When much of this work is to be done, the cost will be less if a special machine is made for the article.

Electric Brazing. Electric brazing can be done quickly by placing the parts in a butt- or seam-welding machine, heating the

joint, and then applying the spelter and flux, allowing them to run into the joint. The temperature can be controlled more easily than by any other process, and the work is always in sight. It would seem, however, that welding would be preferable to brazing.

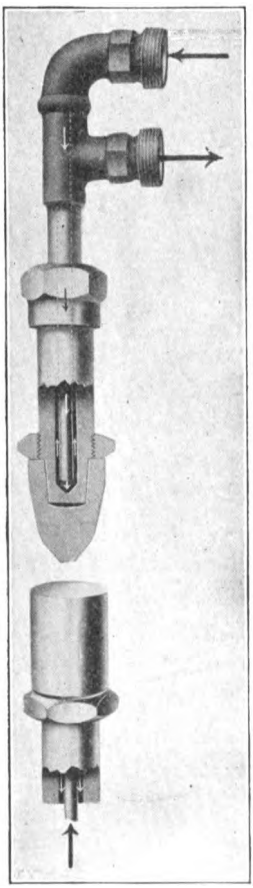


Fig. 53. Water-Cooled Die Point
Courtesy of Toledo Electric Welder Company

Hardening and Tempering. Hardening and tempering can also be done by heating the pieces in a butt-welding machine and, when the desired color is reached, chilling in the usual manner. The advantage in this process lies in the fact that the work is always in sight.

Electric Riveting. Electric riveting is another recent variation of the spot-welding process and consists in making the holes in the pieces, inserting the rivets, heating them between the tips of a spot welder, and then pressing them to form heads while soft. It is very quickly done and eliminates the rivet heating furnace; for heavy work it is good, but is more expensive than straight spot welding for thin plates.

General Matters of Good Practice. *Freedom from Dirt and Grease.* When doing either butt or spot welding or any of their variations, it is important to see that the surfaces are cleaned thoroughly before starting to weld them because the presence of grease, dirt, or other matter between the surfaces will prevent a perfect joint. The cleaner and better the stock, the easier it is to weld, the less current it takes, and the less wear on the dies. Dirt, grease, and scale are insulators, in most cases, and it takes only a small amount, at the low voltage used, to prevent the flow of current; if there is any undue heating in any part of the machine where there is a joint in the circuit, it should be carefully examined for dirt and grease and then cleaned. Bolts frequently work loose and, allowing oil to carry dirt under their

heads, cause heating. There is no danger of a shock from the welding circuit because of the low voltage, but the line, or primary side of the machine, should be avoided, if possible, or handled with proper precaution.

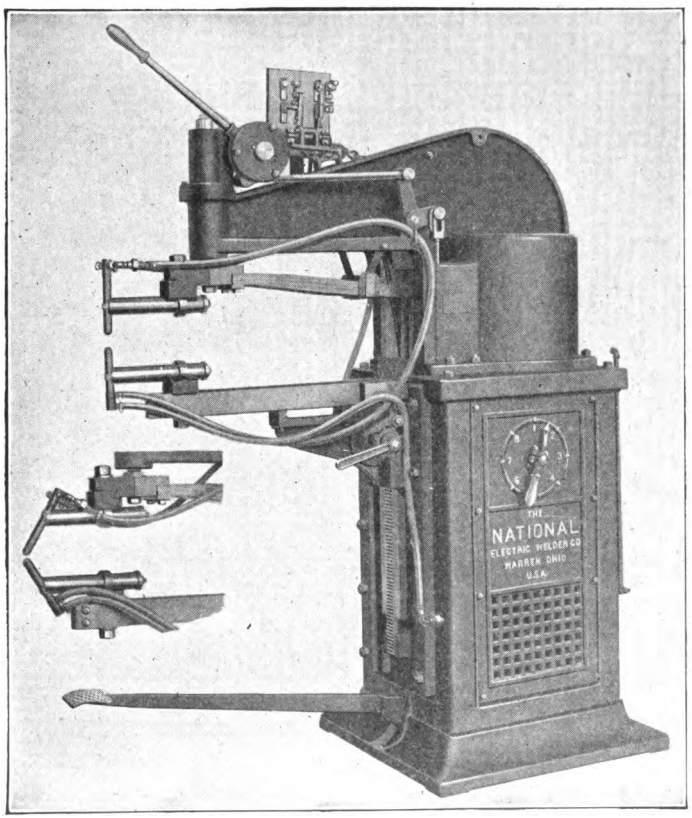


Fig. 54. 24-Inch Drop Arm Spot Welder Showing Different Positions of Universal Points
Courtesy of National Electric Welder Company

Avoiding Heating of Parts. If the machine has been properly installed, there should be no trouble so long as the cooling water flows through the welding dies, Fig. 53, and everything is kept clean and all connections tight. The only moving parts on most contact welders are the clamps and jaws, Fig. 54, and these are easily watched; the transformer is so simple it should never get out of order except in cases of accident. The switches should be

enclosed to prevent accidental contact, and ordinarily they are automatic and out of reach.

ELECTRO-PERCUSSIVE PROCESS

Development of Method. The development of electro-percussive or percussion welding began in 1905 while L. W. Chubb, of the Westinghouse Electric & Manufacturing Company, was experimenting with electrolytic condensers. He found that wires of aluminum or copper could be attached to plates of these and other metals if subjected to the action of the discharge from the condensers at the instant of contact. Joints formed in this way were not strong mechanically, so further experiments resulted in the development of the device shown in Fig. 55, which looks very much like a miniature pile driver.

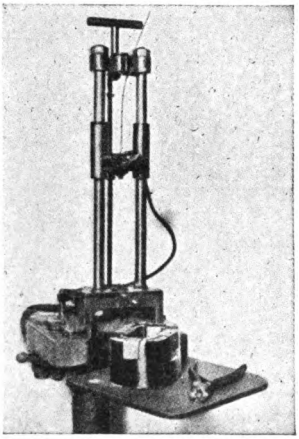


Fig. 55. Portable Percussion Welder

Action. The action also is very much like that of a pile driver. The apparatus consists of a stationary base and terminal clamp, uprights to guide a moving terminal block and an upper or moving clamp which drops down to perform the operation. One of the wires or parts to be welded is clamped in the lower terminal and the other part in the upper terminal. Suitable electrical connections are made, and the upper clamp drops down and brings the two parts into contact and allows the condenser to discharge through them, thereby fusing the metals instantly and welding them.

This is the only type of butt welder which uses direct current, and for even small wires the current may be several hundred amperes momentarily. Satisfactory operation depends upon the capacity of the condenser, velocity and force of impact when bringing parts together, voltage used, resistance and inductance inserted in the circuit. All these factors may easily be varied to suit the job in hand. Although a relatively large current is developed during the discharge, the duration of the impact is for

such a short time that the apparatus can be of small size. For example, a maximum of 23 kilowatts is developed when welding a No. 18 copper wire, but as the work is done in 0.0012 second, the current is only 0.00000123 kilowatt hour.

In Fig. 56 are shown the connections and elements of a complete percussion welding outfit. Fig. 57 shows how the parts look when set up for operation. For certain purposes, such as welding the parts of spectacle frames and other pieces of odd sizes and shapes, welders with special terminal clamps must be used, but the action must be the same for all purposes. This process is especially good for aluminum because the oxide is thereby forced out and a good joint insured. Tin and lead seem to be the only metals which do not give satisfactory welds.

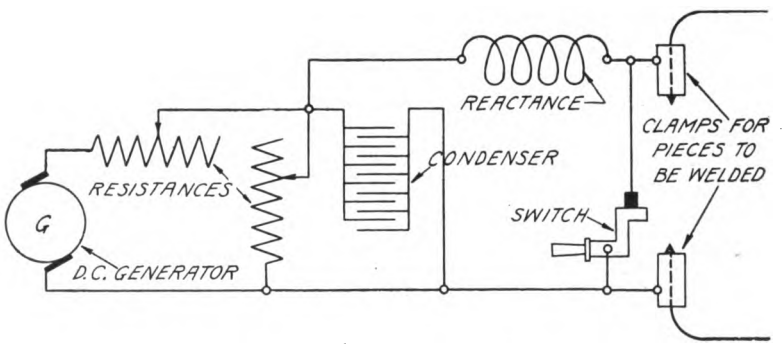


Fig. 56. Diagram of Percussion Welding Set

Welds made between other metals last several years without showing deterioration or change.

For best results, the ends of the wires or other pieces to be welded should be cut off with a pair of pliers close up to the clamps, and cut so that the ridges formed will be at right angles to each other. This insures the minimum contact at first and causes greater heating and fusion. The weight and dropping distance of the upper, or falling, chuck must be enough to insure mashing or forging of the joint; and the voltage and inductance must be adjusted until the discharge sounds like a thud or splash instead of like a sharp crack. This can readily be determined with a little experience, and practically all metals may be welded with no appreciable loss or change of properties.

APPLICATIONS OF WELDING TO MANUFACTURE

General Applications. The applications of welding to manufacture are too numerous to mention here. Among the more important articles made by welding are wagon tires, axles, iron wheels, bicycle parts, pedals, brake parts, chain adjusters, tools, shovels, printers rolls, wire and strip hoops, screens, special piping, rail bonding, as shown in Figs. 58 and 59, rings and chains, automobile parts, steering knuckles and rods, step brackets, valve heads and stems, typewriter bars, sheaves and pulleys, umbrella rods, frames, Fig. 60, structural iron work, stovepipe, knives, steel enameled ware, etc. Practically every kind of metal can be welded and every shape or section that can be put into the machine can be manipulated if the surfaces can be brought together. Special machines for welding the joints in track rails have been devised, and Fig. 61 shows the cars and other details of the equipment required. A large spot welder, the details of which are shown in Fig. 62, is used and is made so that the jaws hang vertically down from a crane, with a transformer suspended between them. Pressure is applied through a hydraulic cylinder and plates are welded to each side of the web of the rail. The top of the rails is ground smooth after welding.

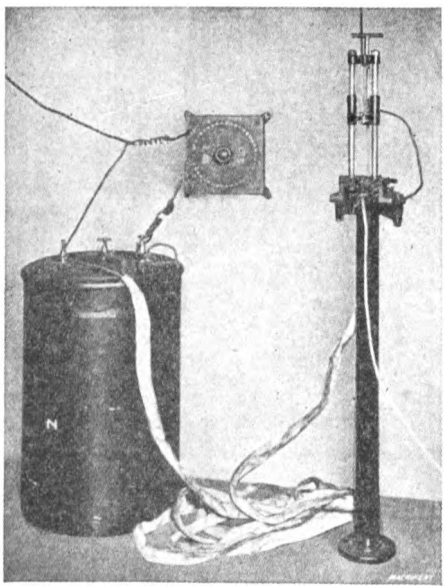


Fig. 57. Percussion Welder, Condenser, Rheostat and Connections

When welding hoops, Fig. 47, the strip is bent around and the ends brought together and clamped in the jaws of a butt welder. Most of the current will cross the joint, because the jaws are set close and the path across the joint offers the least resistance, although a part of the current will go around the hoop.

Chains are welded in the same manner, Fig. 63, and the work is successful in spite of the short length of circuit around the link.

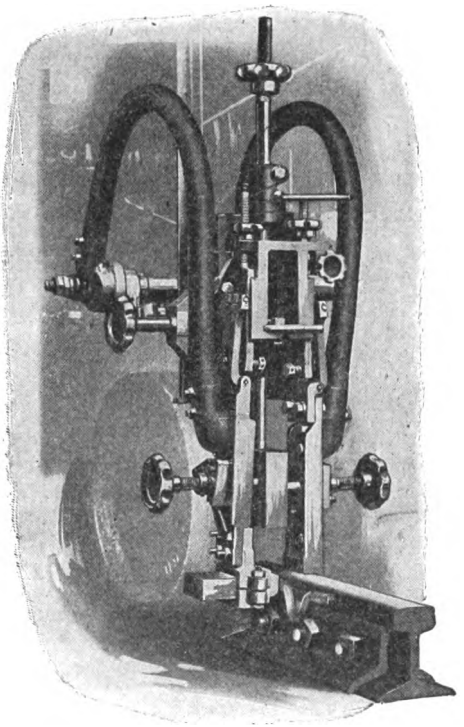


Fig. 58. Spot Welder for Bonding Rails
Courtesy of Electric Railway Improvement Company

Automatic machines are sometimes used for chain making, wire fencing, screens, and other articles requiring a repetition of numer-

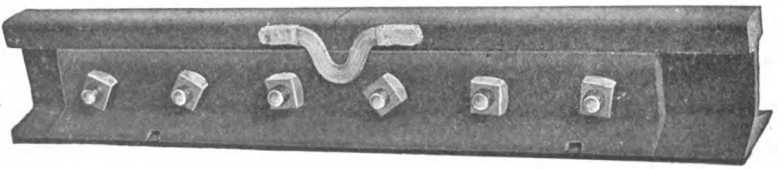


Fig. 59. Bonded Rail
Courtesy of Electric Railway Improvement Company

ous simple joints, Fig. 64. Sheet steel and aluminum automobile bodies, mud guards, bonnets, and other parts are spot welded.

Coffee pots, Fig. 65, kettles, and similar articles have their spouts and handles spot welded on, and coal pails, wheelbarrow bodies, spiral piping, coal chutes, boxes, cabinets, lockers, steel shelving, and hundreds of other articles offer almost unlimited opportunities for welding by this system. Butt welding is used to almost as great an extent as blacksmith welding and is much cheaper.

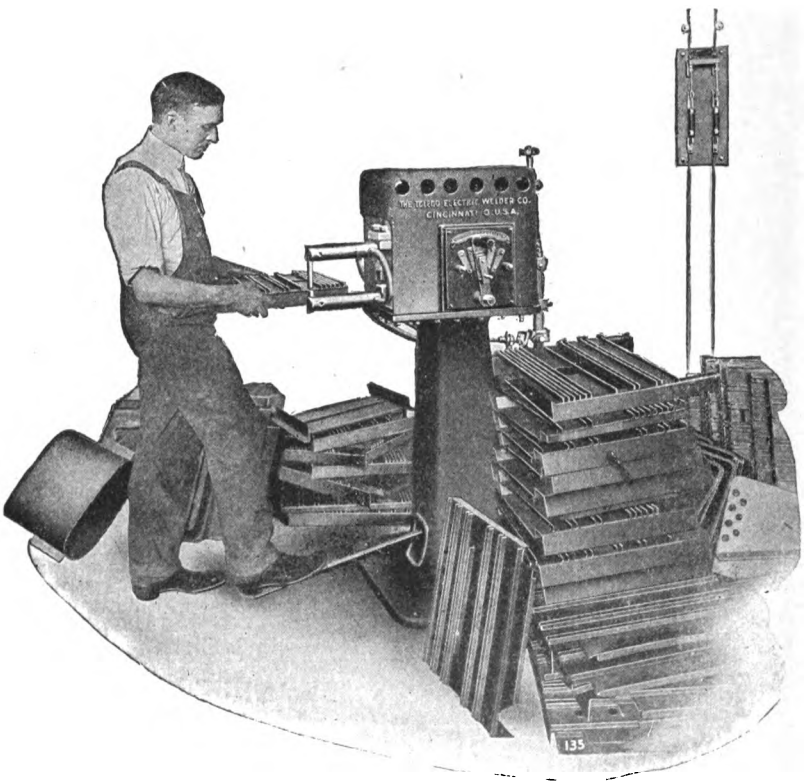


Fig. 60. Spot Welder for Pressed Metal Frames
Courtesy of Toledo Electric Welder Company

Practice with Different Metals. *Iron and Steel.* Iron and steel are used more than any other metals and are, therefore, the metals most commonly welded by all processes; fortunately they are about the easiest to weld. For butt-welding iron or steel the stock should be clamped in the dies with comparatively little projection and the ends brought together before switching on the current. Considerable pressure is required because it is better

to keep the temperature below the melting point. For an upset weld the dies should be about 1 inch apart and for a flash weld they should be about $\frac{1}{4}$ inch apart for ordinary sections.

Cast Iron. Cast iron cannot be welded commercially by this process because of its crystalline structure and the high percent-

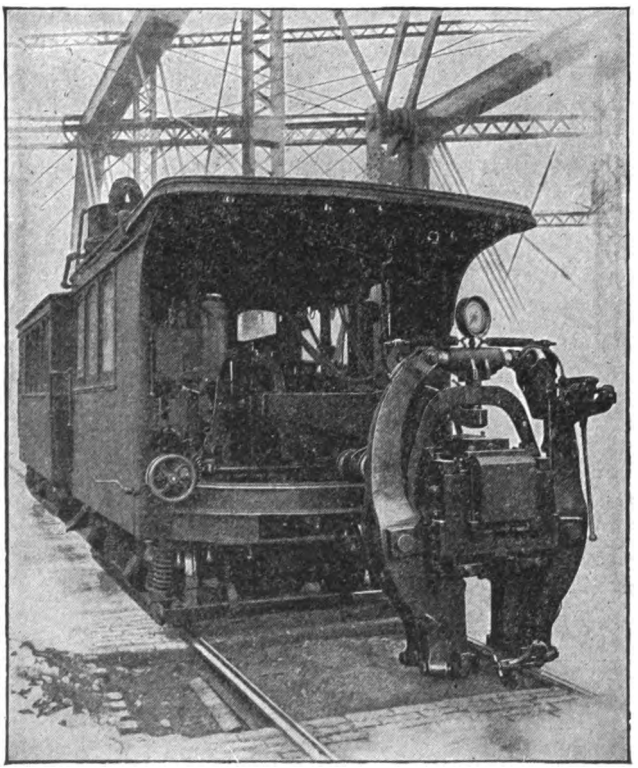


Fig. 61. Electric Rail Welder and Car
Courtesy of Lorain Steel Company

ages of carbon and silicon in its composition. The arc-welding process is the one to use for cast iron, as the metal passes readily from the crystalline to the fluid state when sufficiently heated, which is a disadvantage for butt or spot welding.

High-Carbon Steel. High-carbon steel can be welded by this process, but must be annealed afterwards to relieve the stresses set up by the localized heating. A good joint can always be made with steel of .25 per cent carbon or less, frequently with

steel containing up to .75 per cent carbon, but seldom with that containing more than .75 per cent. It requires an experienced operator to get good results with high-carbon steel because it is so easily injured. High- and low-carbon steels can be welded together successfully by good operators, if the low-carbon stock is allowed to project further through its die than the high-carbon steel.

Nickel Steel. Nickel steel may be welded readily, and the strength is high.

Copper and Brass. Copper and brass may be welded and have the joint strong enough to stand the strain of redrawing

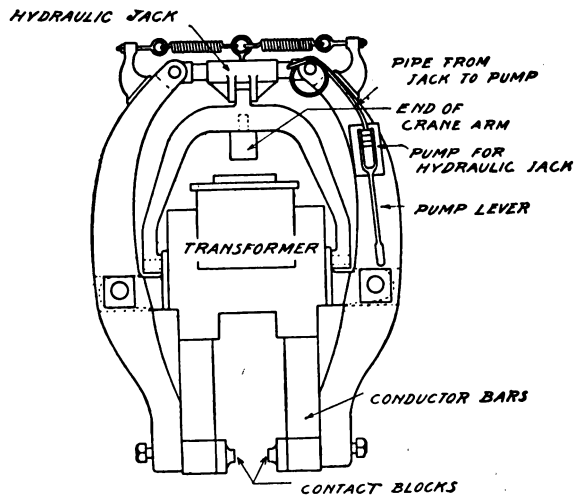


Fig. 62. Diagram of Lorain Rail Welder
Courtesy of Thomson Electric Welding Company

through dies but the pressure, when welding, must be less than for iron. The metal is really allowed to fuse, or melt, at the joint and the pressure should be just sufficient to force out the burnt metal. It is because of this that good welds are possible, but the current must be shut off as soon as the ends of the pieces soften, and an automatic switch is provided for this on some machines. The dies should be set apart 3 or 4 times the thickness of the stock and more current should be used than for iron.

Iron and Copper. Iron and copper can be welded together, if the section of the copper is less than the iron at the point of contact, as the former is a better conductor.

Galvanized Iron. Galvanized iron of No. 22 gage and heavier can be spot-welded but it will burn the zinc off at the welded spot and on both sides of the sheets. For thinner sheets it does not pay to try welding by this method.

Sheet Brass. Sheet brass can be welded to brass or to sheet steel after sufficient experimenting to determine the proper heat and pressure.

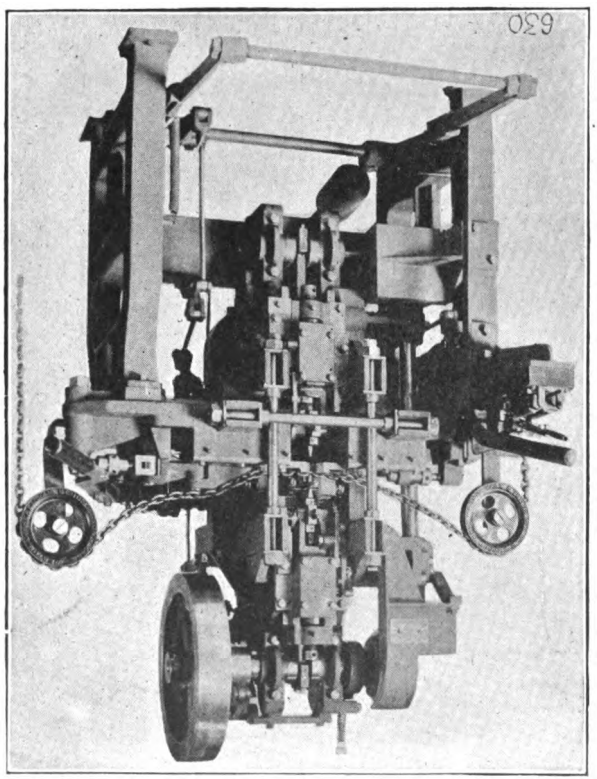


Fig. 63. Semi-Automatic Chain Welder
Courtesy of Thomson Electric Welding Company

Sheet Aluminum. Sheet aluminum of some grades can be spot-welded, but the surface will be rough and pitted where the die points touch it.

Sheet Copper. Sheet copper is hard to weld because of its low resistance, but it can be done by an experienced operator using sufficient current.

TABLE XI

Power and Time for Butt Welding

Iron and Steel				Brass				Copper			
Area Sq. In.	Power Kw.	Seconds	H. P.	Area Sq. In.	Power Kw.	Seconds	H. P.	Area Sq. In.	Power Kw.	Seconds	H. P.
.25	6.	20	8.	.125	6.	10	8.	.0625	5.	5	7.
.50	10.	28	13.5	.25	12.	14	15.7	.125	8.5	7	11.5
.75	13.	35	17.5	.375	12.6	17	17.	.1875	12.	9	16.
1.00	18.75	40	25.	.50	15.	20	20.	.250	18.	10	24.0
1.50	29.5	44	39.5	.75	25.	22	33.5	.375	28.5	11	38.
2.00	33.	57	44.0	1.00	29.5	28	39.5	.500	32.	14	43.
2.50	38.	63	50.	1.25	37.	32	50.	.625	37.	16	50.
3.00	43.5	70	58.5	1.50	43.	35	52.7	.75	43.	18	52.
4.00	56.3	80	76.	2.00	53.	40	71.	1.00	55.5	20	75.
5.00	61.7	90	83.	2.50	60.	45	80.	1.25	61.	23	82.
6.00	69.	98	92.5	3.00	66.	49	88.5	1.50	68.	25	91.

Limits as to Thickness of Metal. There is a limit to the thickness of sheets which can be spot-welded and to the sectional

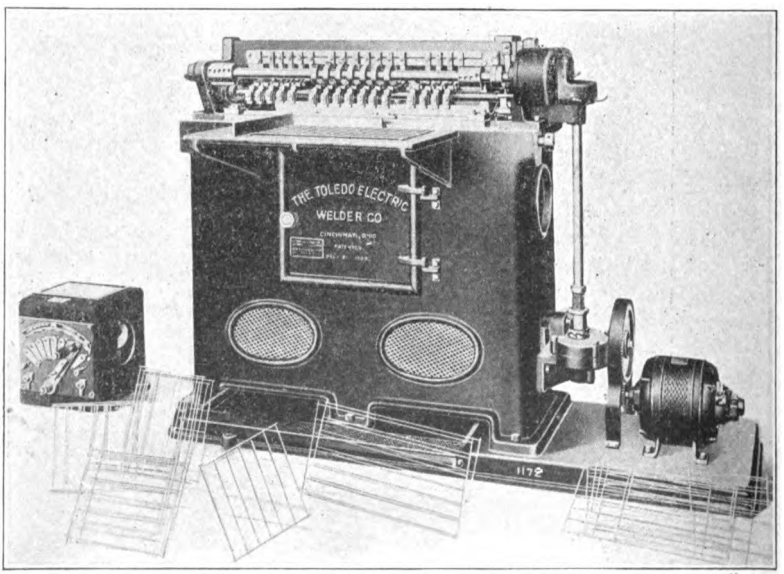


Fig. 61. Electric Welder Capable of Welding Sixteen Wires at One Time
Courtesy of Toledo Electric Welder Company

area of pieces which can be butt-welded because of the heating of the dies or clamps by the large amounts of current required for

TABLE XII

Butt Welder Data

Rd. Iron Diameter in inches	Area in Square Inches	Kw. Required	H. P. at Dynamo	Time in Seconds to Make Weld	Cost per 1000 Welds at 1 cent per Kw.
1/4	.05	2	3	3	0.02
3/8	.11	3.5	5	5	.05
1/2	.20	5	7.5	5	.07
5/8	.31	7.5	12	10	.21
3/4	.44	12	17	15	.50
7/8	.60	15	22	18	.75
1	.79	18	25	20	1.00
1 1/8	.99	25	35	25	1.73
1 1/4	1.23	35	50	30	2.90
1 1/2	1.77	50	70	40	5.55
1 3/4	2.41	65	85	45	8.12
2	3.14	75	100	50	10.42

As the rate charged for current varies in different places, we have figured the current at one cent per Kw. hour to give a basis for calculating the cost. Multiply the prices given above by the rate per Kw. hour charged by your local electric light company, and that will give your cost for current for 1000 welds. Labor cost must be added.

heavy work. If enough cooling water is passed through the dies to prevent overheating, it will also carry off some of the heat from the work and a point is soon reached where the area of contact of the dies becomes so great as to be a disadvantage. Theoretically, it is possible to weld any size section with a comparatively small current by leaving it on long enough, but in practice we must take radiation into account, for a point is soon reached where radiation equals the heating effect of the current and, at this point, the temperature remains constant.

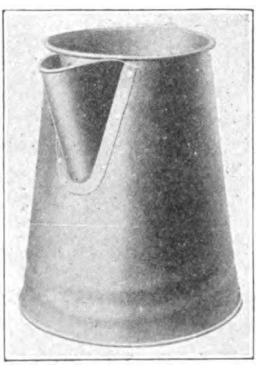


Fig. 65. Coffee Pot with Spot-Welded Spout

Power Required. The power required for butt and spot welding is easily determined from the cross section and material of the piece, because considerable experimental data is available. As previously stated, the power required for this kind of welding varies inversely as the time consumed in making the weld. This means that the longer you can take to do the work, the less current you will require; and

TABLE XIII

Spot Welder Data

Gages of Sheet Steel	Thickness in Fractions of an Inch	Thickness in Decimal Parts of an Inch	Approximate Kw. Capacity	H. P. at Dynamo	Time in Seconds to Make a Weld	Cost per 1000 Welds at 1 Cent per Kw.
28	1–64	.015625	5	8	.3	.0045
26	3–160	.01875	6	9	.4	.0065
24	1–40	.025	7	11	.5	.01
22	1–32	.03125	8	13	.6	.0135
20	3–80	.0375	9	14	.7	.0175
18	1–20	.05	10	15	.8	.0225
16	1–16	.0625	12	18	.9	.030
14	5–64	.078125	14	20	1.	.039
12	7–64	.109375	16	23	1.3	.058
10	9–64	.140625	18	25	1.5	.075
9	5–32	.15625	20	30	2.	.112
8	11–64	.17187	23	34	2.5	.16
7	3–16	.1875	25	37	3.	.21
6	13–64	.20312	28	42	4.	.31
5	7–32	.21875	30	45	5.	.42
4	15–64	.23437	33	48	6.	.55
3	1–4	.25	35	53	7.	.68

Based on using fairly clean stock, this table will give an idea of the time and current required in welding different gages of sheet steel.

As the rate charged for current varies in different places, the current has been figured at one cent per kw. hour to give a basis for calculating the cost. Multiply the prices given above by the rate per kw. hour charged by the local electric light company, and that will give the cost for current for 1000 welds in any given locality. Labor cost must be added.

the quicker you wish to accomplish the work, the more current you must use. The total amount of energy in kilowatt hours will be the same in either case, but a larger transformer must be used for rapid work.

Tables XI, XII, and XIII will give a good idea of the power and time required for various thicknesses of metal with butt welding and spot welding, and it will be well to compare the effect of time on the current used.

Table XII is different from Table XI for similar sizes of section because of the difference in the time taken per weld.

Table XII is based only on the use of iron rods, the diameters being given in Column 1. Table XIII is based upon steel, but in the form of sheets. The costs of making the welds as given in Tables XII and XIII are very interesting and should be carefully noted.

Cost of Butt and Spot Welding. The cost of welding by both butt and spot methods can easily be figured from Tables XII and XIII by determining the cost of current for the operating conditions under consideration and adding the required amount for labor and overhead charges in the shops. The latter item is very important and will have a noticeable influence on the cost of welding in most shops. The labor for handling the material to and from the welding machine is just as important as that of the operator himself, and the cost of such labor, together with the interest and depreciation on the purchase price of the welding machine and the cost of installing, are part of the overhead expense. Articles of special shapes will require different amounts of current and experiment alone will show the current required; this factor, with the labor and overhead expenses, will give the cost. It will be self-evident that the better provision one makes for handling the work, the lower will be the cost per unit produced.

Strength of the Weld. The strength of the weld should equal from 75 per cent of the original material on heavy stock up to 95 per cent of it on light stock, when finished to the same diameter or thickness as the piece; this can be made 100 per cent or greater, if a reinforcement can be left on in the form of an upset. The strength of a weld is slightly increased by working after welding, unless there is too much carbon or silicon in the iron. The metal is not damaged by welding with either the butt- or spot-welding systems, if properly done, because the heat can be controlled so exactly. The oxide which may be present at the joint is usually forced out into the upset and ground off; so a burned weld is a rare thing with this system. In the early days of the Thomson system, there were complaints of weak spongy burnt welds, when made by butt welding, but this was largely due to inexperience and the tendency to heat the metal too much. If an excess of heat is applied, either by using too high a current or leaving it on too long, the metal may be weakened within the heating radius and break about an inch from the joint.

Watertown Arsenal Tests. A number of years ago, a series of tests on electric welding was conducted at the Watertown Arsenal, and the following results were reported in the *Transactions of the American Society of Mechanical Engineers* for 1898:

Wrought-iron welds averaged from 5 per cent to 10 per cent below that of the plain bars and the fractures were either fibrous or slightly spongy.

Steel welds showed a strength of only 20 per cent to 50 per cent of the original.

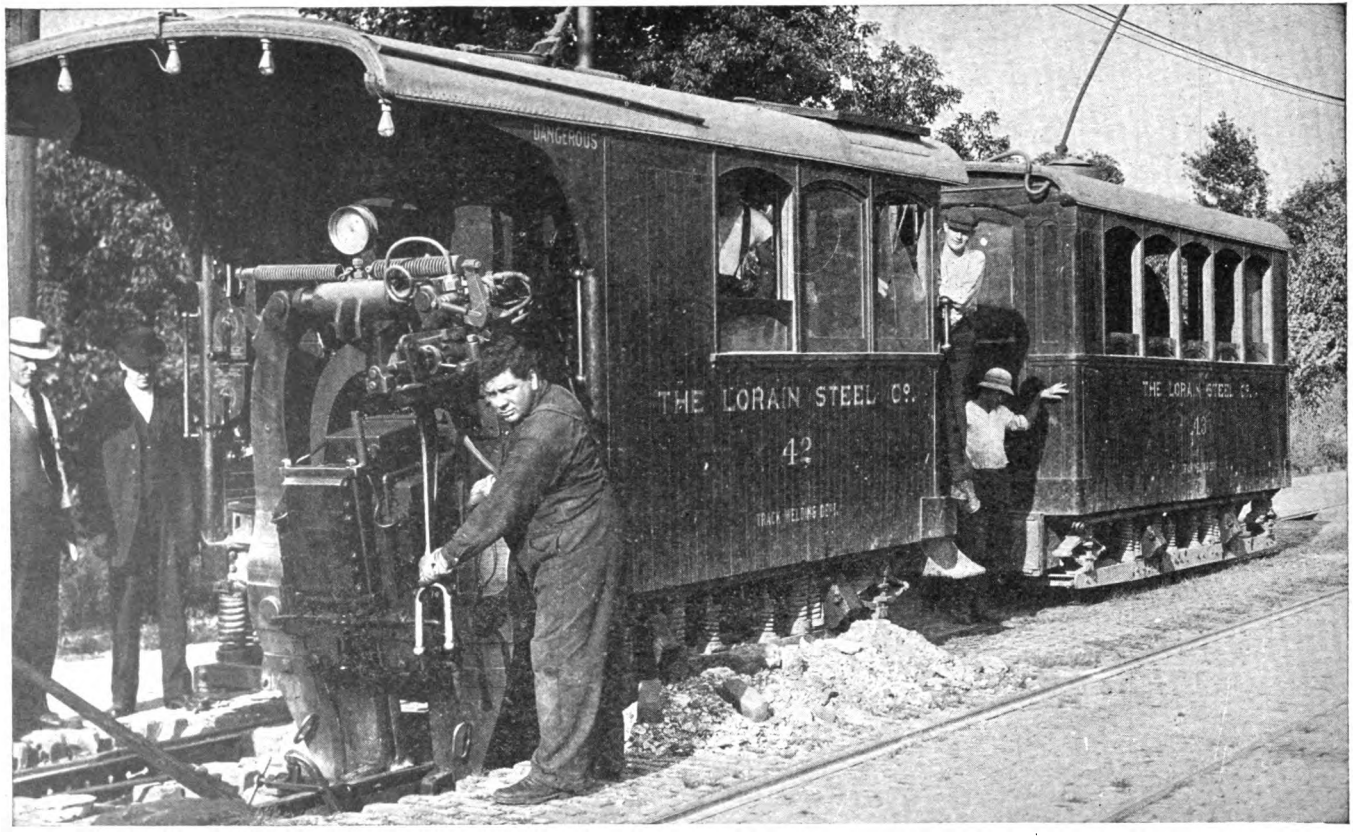
Steel welded to wrought iron showed a strength equal to the iron.

Copper showed a strength of from 90 per cent to 95 per cent of the original stock.

Brass and wrought iron gave very uncertain welds and low strength.

Out of sixty samples welded, twenty-nine broke in the weld; seventeen, within two inches of the weld; eleven, within the range of moderate heat; and two broke near the grips of the testing machine.

Manufacturers of Butt and Spot Welders. There are several firms making butt- and spot-welding apparatus in this country today, and it will pay the student to get data from all of them. The principal companies are the Thomson Electric Welding Company, Lynn, Mass.; Geuder, Paeschke & Frey, Milwaukee, Wisconsin; National Electric Welder Company, Warren, Ohio; Toledo Electric Welder Company, Cincinnati, Ohio; and Winfield Electric Welding Machine Company, Warren, Ohio. All these makers have several forms of machines which are adapted to particular lines of products.



TRACK WELDING MACHINE IN OPERATION

WELDING

PART II

GAS WELDING AND CUTTING

General Features of Method. Hot-flame, or gas, welding and cutting has been a practical process for so long that there is no very clear record as to just when it first came into commercial use, but it has only been within the last fifteen or twenty years that apparatus for the generation of welding gases have been developed. These have given an added impetus to the art of gas welding. The process of gas welding consists merely in joining metals by fusing them together with the aid of a high-temperature gas flame as the source of heat.

Defining Terms. There are two methods of welding in general use, the "Autogenous" and the "Heterogeneous," the names indicating clearly the main difference. The word "autogenous" signifies that the weld is made by the fusion or junction of the articles themselves, without the use of outside filling material to complete the joint. The word "heterogeneous" means a mixture, and signifies that the weld is made by fusing-in some sort of additional filling material, instead of depending entirely upon the metal of the pieces themselves. It is obvious that, if the filling material is of a metal different from the pieces welded, we still have heterogeneous welding; so this name can be correctly applied to brazing or soldering. Custom makes laws, it is said, and custom limits the term "welding" to cases where the same metal is used for a filler as is used in the article welded, and that is the way the term is used here. The term "autogenous" has, unfortunately, come to be applied to all forms of gas welding, and some confusion has resulted because the statement is made that neither flux nor hammering is necessary with that process. The truth is, that fluxes are very beneficial when welding some metals, and hammering helps the strength of welds in heavy pieces because it tends to change the structure of the metal from a coarsely crystalline to a finer structure.

Advantages Claimed. The principal advantages claimed for gas welding are: the simplicity of the process; low first cost of the apparatus; wide range of applicability; light weight of the parts; ease of portability, if necessary; high temperature of the flame; and flexibility of the process for heating purposes. The limitations of the process are: the danger from using an exposed flame; the liability of explosion of the gas tanks and generators; oxidation or carbonization of the weld by the flame; crystallization and cracking of the weld when cooling; and high cost of operation as compared with electric welding. The danger from explosions is being reduced gradually by improved apparatus and the restrictions imposed by the Board of Fire Underwriters.

GASES USED FOR WELDING

Gases and their sources form a very important part of the study of the gas-welding processes, and a knowledge of these will often be of great value in determining the best process for particular purposes. The gases originally used for welding were probably oxygen and hydrogen, and efforts to liquefy them were made about one hundred years ago in order to simplify the means of storing them. It took about fifty years to develop a good process for doing this and resulted in the development of one of the principal present-day methods of producing oxygen.

Combinations of Gases with Oxygen. Most of the gas welding today is done with systems using oxygen in combination with another gas; and the processes take their names from the gases used. The leading processes are known as the oxy-acetylene, oxy-hydrogen (or oxy-hydric), blau-gas, oxy-pintsch gas, water-gas and coal-gas welding processes, the oxy-pintsch-gas process being the latest development. All these processes depend upon the use of compressed gases, usually stored in strong cylinders and mixed in a burner or torch. They serve for both cutting and welding.

Oxygen. Oxygen, the most important of all of the elements, is used as one of the gases in nearly all welding processes. It was discovered in 1774 by Priestley and Scheele, each working independently, and in 1789 Lavoisier proved that its presence was necessary for combustion in the air.

Methods of Commercial Production. Oxygen is produced commercially by three methods: from the air by liquefaction and fractional distillation; from water by electrolytic action; and from potassium chlorate. The production of *oxygen from air by liquefaction* is by far the greatest source of this gas today for welding purposes, though electrolytic apparatus has recently been developed which is making a strong competitor where power is cheap. The oxygen used for welding must be free from chlorine, although the usual mixture of 5 per cent of nitrogen and from 2 to 3 per cent of hydrogen is no disadvantage. Its production is not a very complicated process, but the apparatus is rather expensive.

The principal process for producing oxygen from the air is that developed by Linde and consists in liquefying the air and separating the nitrogen and oxygen by fractional distillation, similar to rectifying spirits. Liquid air is 80 per cent nitrogen and 20 per cent oxygen. Commercial oxygen is 95 per cent pure; the rest is nitrogen, which is not harmful for welding purposes.

Oxygen is sold in tanks containing 5, 25, 50, or 100 cubic feet, as desired. The tanks may be either bought or rented and recharged when empty. Each tank is equipped with a reducing valve to regulate the pressure. A pressure gage is necessary when using the oxygen, and leakage must be looked out for because of the high pressure.

The production of oxygen by the *electrolytic decomposition of water,* the method used most in Europe, gives two volumes of hydrogen to one of oxygen. The process consists in passing a direct electric current at a pressure of 2 or 3 volts through an electrolyte or solution of sodium or of potassium hydroxide. From 240 to 325 amperes are used. Oxygen rises from the water around the positive terminal plate and hydrogen from around the negative plate, and each gas is conducted through separate pipes to compressors for storage. The gases are about 99 per cent pure. Purity is important; if foreign matter is present it is likely to burn into the weld.

The apparatus for making *oxygen from potassium chlorate* is comparatively simple and low priced. The process is based on the fact that, when potassium chlorate is heated, it produces a somewhat large percentage of oxygen of 97 to 98 per cent purity.

One pound of chemicals costing about 8 cents will produce about 4½ cubic feet of oxygen at a total cost for everything of about 2¼ cents per cubic foot of gas. It is compressed into steel cylinders at 300 pounds per square inch for service. The makers of this apparatus claim that because of the low pressures used there is but little oxygen lost through leakage.

Acetylene (C_2H_2). Acetylene is a colorless gas with a very disagreeable odor very largely due to the impurities present. It was first obtained by Davy in 1837 when making potassium. Wohler produced calcium carbide in 1862 by fusing lime, zinc, and carbon together, and then obtained acetylene by adding water to the carbide. Acetylene was first liquefied by Cailletet in 1877 and the use of compressed acetylene was developed by Claude and Hesse. Today, acetylene is obtained almost exclusively from calcium carbide and water, and great care must be exercised to see that pure carbide is used in order to prevent the generation of phosphureted hydrogen along with the acetylene.

Calcium Carbide (CaC_2). Calcium carbide is a dark gray slag formed by fusing lime and coke in the intense heat of an electric furnace; it possesses a great affinity for water. When calcium carbide is combined with water (H_2O) in the proportion of two parts water to one part carbide, a chemical reaction takes place which heats the mass and forms acetylene (C_2H_2) and lime ($CaOH_2O$) in the form of ashes. In other words, the carbon combines with the hydrogen to form acetylene and the calcium combines with the oxygen to form lime. One pound of carbide will yield about four and one-half cubic feet of acetylene.

Methods of Storing Acetylene. When mixed with air, acetylene is explosive over a long range of proportions, and this makes the gas very troublesome. It is explosive over the limits of two per cent gas and 98 per cent air up to 49 per cent gas and 51 per cent air and, when mixed with oxygen, it burns with a tremendous heat.

Acetylene is readily soluble in liquid acetone, which is cheap, inert, and incombustible; so storage cylinders or tanks are partly filled with it and then the acetylene gas is compressed into it. Acetone at atmospheric pressure and a temperature of 15 degrees centigrade will dissolve 24 times its own volume of acetylene and,

at 12 times atmospheric pressure (180 pounds), it will dissolve about 300 times its volume of acetylene and expand about 50 per cent. The cylinders are partly filled with asbestos fiber to carry the acetone. To fill the cylinder, it is merely necessary to charge it with compressed acetylene.

Hydrogen. Hydrogen is one of the elements and is the lightest substance known. It is usually obtained by the decomposition of water into oxygen and hydrogen, both gases being collected and used. Hydrogen may be liquefied and, when mixed with air or oxygen, is explosive. It is not poisonous but may cause death if inhaled because it will exclude oxygen from the lungs. When hydrogen and oxygen are mixed to form a gas in welding and cutting, they produce a temperature of about 2500 degrees centigrade.

Blau Gas. Blau gas is liquefied illuminating gas and is produced by the distillation of mineral oils in red-hot retorts. It contains carbon and hydrogen in the proportion of about 5 parts of carbon to 1 part hydrogen and will develop about 20 per cent more heat units than acetylene. Blau gas, named after its inventor, can be compressed and liquefied; when liquefied it occupies but 1/400 part of its gaseous volume and is usually sold under a pressure of 100 atmospheres, in steel cylinders. It is very inert and therefore difficult to explode, the range of explosiveness being from 4 per cent gas and 96 per cent air up to only 8 per cent gas and 92 per cent air. This gas is already used quite extensively abroad, and is beginning to be used more and more in this country.

Pintsch Gas. Pintsch gas was originally developed for lighting purposes and is today used for lighting steam railway cars. It is an oil gas made from crude petroleum or similar oils and will safely stand a high degree of compression. It is used at various pressures for different purposes. Works for the supply of the gas are now established in nearly all of the large cities in the United States, Canada, and Mexico, and the gas can be obtained under pressures up to 100 atmospheres (1500 pounds pressure per square inch). It can also be obtained, in flasks, under pressure of 12 atmospheres (180 pounds per square inch), but it is used at a pressure of about 25 pounds per square inch for cutting and weld-

ing. On account of its high heating value and its stability, or resistance to preignition, it is coming into use for high-temperature work in conjunction with oxygen, and it bids fair to become a serious competitor of acetylene.

Water Gas. Water gas, a mixture of carbon monoxide and hydrogen, is formed by passing steam over or through incandescent coke, thus causing the steam to decompose into oxygen and hydrogen. The oxygen combines with carbon from the coke and forms carbon monoxide, with a little carbon dioxide, and a slight impurity in the form of hydrogen sulphide from the sulphur in the coke. The impurity can be removed with lime or iron oxide, as is done in the manufacture of coal gas. On an average, thirty-five pounds of coke are used for each 1000 cubic feet of gas.

The apparatus for generating water gas is comparatively simple and consists mainly of a generator and a superheater, with connections for taking off the gas and for supplying air and steam. Water gas gives an extremely high temperature when burned, and it is used a great deal in Europe for heating metals preparatory to welding by hammering as well as for fusing, as in some other processes. Owing to its lack of odor when pure, it is dangerous if it escapes.

Coal Gas. Coal gas, or illuminating gas, is produced by the destructive distillation of coal. Its discovery dates back to 1727. It is made by heating coal to the point where it decomposes, in a closed retort in order that the gas, tar, and other constituents may be saved. Bituminous coal is better for gas making than anthracite, as it softens, or fuses, at a temperature much lower than that required for combustion; and this fusion is the commencement of the destructive distillation which forms the solid, liquid, and gaseous compounds from the coal. One ton of coal will produce about 10,000 cubic feet of gas, 1400 pounds of coke, 12 gallons of tar, and 4 pounds of ammonia, the operation lasting about 4 hours. The gas contains about 5 per cent of hydrocarbon vapors, 13 per cent of carbon oxides, 31 per cent marsh gas, 46 per cent hydrogen, and 5 per cent nitrogen with traces of oxygen and has a heat value of about 40 per cent that of acetylene. Its use for welding is limited.

OXY-ACETYLENE WELDING

General Features. The oxy-acetylene welding process is the best known of the hot-flame systems. It is based on the combustion of oxygen and acetylene at the tip of a torch. This process has apparently been developed to the highest possible degree and is probably the most efficient of the various hot-flame systems in general use, as the flame has an approximate temperature of 3500 degrees centigrade. When this process was first introduced, its practical value was over-estimated, as it has many limitations. However, the improvements made in torches, valves, generators, and storage tanks should result in improving its status. Owing to the low first cost, there are thousands of oxy-acetylene plants in use for welding and cutting, in spite of the high cost of operating, and reductions in the cost of the gases will eventually bring down the cost of operation to a more reasonable basis.

The principal elements of an oxy-acetylene installation are: the oxygen-generating, or storing, apparatus; acetylene-generating, or storing, apparatus; and the burner, or torch, with its connections. For large plants it will pay to install oxygen-generating plants as well as acetylene plants, but in other shops the oxygen is usually purchased in steel tanks and the acetylene is generated in small-sized outfits. For moderate-sized shops a portable outfit consisting of an oxygen tank and a small acetylene generator, or an oxygen tank and an acetylene tank on an ordinary hand truck can be used.

Acetylene Generator. The acetylene generator is a comparatively simple device, usually a single steel receptacle for holding the gas, with various attachments for controlling the action of the water on the carbide. There are two general systems of acetylene welding in use, the high-pressure system and the low-pressure system, both of which have their advocates. As a matter of fact, the so-called high-pressure system used in this country today is a medium-pressure system, the true high-pressure system being used principally in France and not yet having been introduced commercially into this country.

Drop Type. The drop or plunger type of generator is the most economical and satisfactory and has practically superseded all the others. This type of generator is arranged so that the car-

bide falls a few lumps at a time into a large vessel of water, the feeding being done by suitable mechanism; the water absorbs the heat so rapidly that the gas is kept cool and the temperature of the entire outfit is much lower than with other types. The gas is washed by bubbling up through the water; the lime remains in the bottom and is frequently removed. This lime makes a good fertilizer. Theoretically, 1 pound of carbide requires ½ pound of water, but in practice it takes about 1 gallon to the pound for the best results. This should produce 4½ feet of gas. The best known acetylene generator on the market in America today is the Davis generator made by the Davis-Bournonville Company, New York, for use in connection with their welding apparatus, made under the Bournonville patents. Through a hopper at the top the carbide is fed into the machine as required in the form of lumps because ground carbide will produce less gas. The feeding mechanism on top is governed by variations in the gas pressure and its effect on heavy weights and by a moving gas bell. Attached to the tank are also a filter, flash-back chamber, drainage chamber, water filling tube, blow-off valve, and such other devices as are required for the safety and operation of the generator. The pressure of the gas may be varied and can be made to run up to 15 pounds if desired. A portable outfit is shown in Fig. 66.

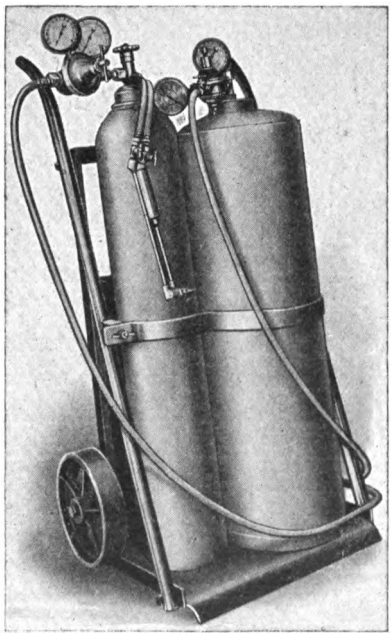


Fig. 66. Portable Welding or Cutting Oxy-Acetylene Unit
Courtesy of Davis-Bournonville Company

Oxygen Generator. Oxygen generators are much more elaborate devices than acetylene generators and the methods of action of the large types have already been given on pp. 83 and 84. Most of the small plants, whose details may be easily understood,

are for making oxygen from chlorate of potassium. They consist of a generator, washer, gasometer, and compressor. From the gasometer the oxygen is carried to a compressor, usually two-stage, and there compressed for filling the cylinders at 300 pounds pressure per square inch. Oxygen of high purity can also be generated by wetting sodium peroxide; small outfits for producing it in this way have been put on the market.

Torch. The torch is the next item of importance in any good acetylene-welding outfit. Upon the development of this device alone has depended the success of the oxy-acetylene process to a large extent. It has taken years to bring torches to their present state, for the flame is very hot and the gases are highly explosive,

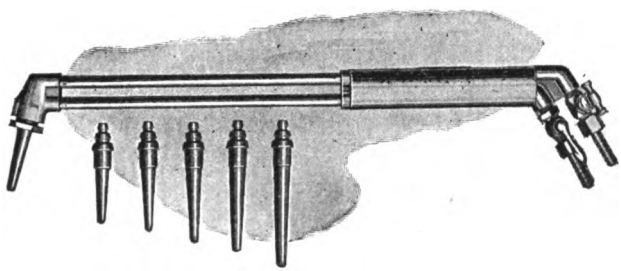


Fig. 67. Medium Welding Torch
Courtesy of Davis-Bournonville Company

yet they must be mixed and controlled accurately. The oxy-acetylene torch was probably invented by Fouche and was a high pressure device; so it was comparatively easy to get a good mixture but, later, it became necessary to develop a torch for low-pressure work and this proved to be a difficult matter. It was done, however, and there are now three styles in use: the original high-pressure torch, the medium- or positive-pressure torch, Fig. 67, and the low-pressure torch. There is also a special torch for cutting with an extra oxygen feed in addition to the regular flame feed.

Goggles for the eyes and gloves for the hands of the operator are necessary for his protection.

Automatic Cutting and Welding Machines. A recent development in connection with oxy-acetylene apparatus is the use of special cutting machines and welding machines which work auto-

matically and displace hand welding and cutting. An attendant is necessary, of course, to see that the material is properly placed. Automatic machines are not of any value for repair work, to be sure, and do not warrant the cost for any other than repetition or straight work. The torch is carried on an arm which is moved by the mechanism of the machine.

Advancement in the art of welding by the various processes is so rapid that improvements in machines and methods are being made almost daily; so the next few years will see as great improvements in gas welding as have been made during the last few years in arc welding. The development of machines for the continuous automatic welding of long seams with gases is an example of what necessity will bring about, and has made the production of welded tubing commercially practicable. Several companies are now using such apparatus.

Cost of Acetylene Welding. The cost of acetylene welding is very moderate on work of small or medium size, but it becomes somewhat high on large work on account of the relative amount of heating to be done while welding. However, considering quantity of production and the money saving in cases of repairs makes the system very valuable in many establishments. The cost of welding sheet steel per foot of length of seam is given in Table XIV, and it will be interesting to compare this with the cost of doing the same work with the electric-arc system. This table was furnished by the Davis-Bournonville Company.

Repair Work. It is difficult to get accurate figures on the cost of doing miscellaneous repair work because the average repair man does not like to tell. The following charges made in one automobile repair shop will give an idea of what such work costs because the profits charged are usually 100 per cent of the cost.

Welding axles, from	$2.00 to $5.00
Cracked cylinder water jackets	8.00 to 12.00
Broken cylinder lug welded on	2.00 to 4.00
Cylinders cracked inside	12.00 to 20.00
Broken crank case, aluminum	5.00 to 20.00
Main side frames broken, each	15.00 to 25.00

Defects, known as "cold shuts," frequently develop in steel forgings, and the average cost of welding these is from 50 cents to $2 each. Engine connecting rods have been welded at $3 to $12

TABLE XIV

Approximate Cost of Oxy-Acetylene Welding

Tip Number	Thickness of Metal in Inches	Consumption of Acetylene in Cu. Ft. per Hour	Consumption of Oxygen in Cu. Ft. per Hour	Proper Pressure in Pounds for Oxygen	Lineal Feet Welded per Hour	Cost of Labor per Hour	Total Cost per Hour	Cost per Lineal Foot
1	$\frac{1}{32}$ to $\frac{1}{16}$	2.8	3.6	8 to 10	50	$0.30	$0.436	$0.0087
2	$\frac{1}{16}$ to $\frac{3}{32}$	4.5	5.7	10 to 12	30	.30	.516	.0172
3	$\frac{3}{32}$ to $\frac{1}{8}$	7.5	9.7	12 to 14	25	.30	.666	.0266
4	$\frac{1}{8}$ to $\frac{1}{4}$	11.7	15.	14 to 18	16	.30	.867	.054
5	$\frac{1}{4}$ to $\frac{5}{16}$	18.	23.	18 to 22	10	.30	1.17	.117
6	$\frac{5}{16}$ to $\frac{7}{16}$	25.	32.	20 to 25	7	.30	1.51	.216
7	$\frac{7}{16}$ to $\frac{1}{2}$	32.5	41.5	22 to 27	5	.30	1.87	.374

NOTE: The acetylene is used at a pressure of about 3 lbs. per sq. in. The cost of oxygen is estimated at 3 cents, and of acetylene at 1 cent per cubic foot. Labor is estimated at 30 cents per hour.

each, according to the size. Stern posts of vessels frequently break in storms and the cost of welding these ranges from $35 for small ones to several hundred dollars for large ones. Blow holes in iron castings cost 25 to 75 cents to fill in.

The student is urged to familiarize himself with the rules laid down by the National Board of Fire Underwriters concerning the installation, care, and operation of oxy-acetylene and other types of hot-flame welding apparatus. The complete rules are too long for reproduction here, but a copy can be obtained from the headquarters of the Board in Chicago, and will be interesting reading.

OXY-HYDROGEN WELDING

The use of oxygen and hydrogen as the gases for welding and cutting is older than the oxy-acetylene process, dating back to before the production of oxygen by either electrolysis or liquefaction of air. Oxygen was probably generated in those days from potassium chlorate and manganese dioxide, or perhaps from potassium and sodium peroxides and water, and the hydrogen from hydrochloric acid and zinc. The oxy-hydrogen process was developed by Newman, who used detonating gas (pure oxygen and hydrogen mixed) at a pressure of about three atmospheres. This gas is still used to some extent in welding platinum, lead, and precious metals but it is rapidly being superseded by apparatus designed to use the oxygen and hydrogen from separate cylinders.

Equipment. The apparatus required for oxy-hydrogen welding is similar to that in use for oxy-acetylene welding. It consists primarily of the two steel cylinders for the oxygen and hydrogen (at pressures of 1500 to 2000 pounds per square inch); a mixer and insulator of the gases, together with a regulator; high pressure reducing valves for each of the gases; armored hose; and the special blowpipe, or torch. When the blowpipe is used, there are two tubes leading to it, one for the oxygen and the other for the hydrogen, and the blowpipe is made with an inner and an outer tube. The oxygen is carried through the inner tube and the hydrogen is carried through the outer tube and lighted first. After the oxygen is turned on, the flame is adjusted to suit the work in hand and the mixing is done in the tip of the blowpipe just before the gases enter the flame. Hydrogen and air can be

used with the same sort of blowpipe for light work requiring but moderate heat, such as lead burning; but the process is much slower and more expensive than that employing the oxy-hydrogen flame.

For commercial welding another type of torch is used and the gases are combined in the mixer and carried to the burner through a single tube. Where the gases enter, the tube has an enlargement which reduces their velocity. From this chamber the gases pass through the smooth tubular body to the nozzle. The latter diminishes in size toward the tip and causes the gas to increase in speed up to the proper velocity.

Handling Oxy-Hydrogen Torch. The oxy-hydrogen flame is pale blue, almost colorless, and has a temperature of about 2000 degrees centigrade. When lighting the torch the operator should turn the hydrogen on about two-thirds and ignite it; he should then turn on enough oxygen to give a pale blue conical flame, and then turn the hydrogen on full. This will take but a few seconds and produce a flame which will not melt the metal too rapidly or be of such intensity as to burn the work. The end of the cone of oxygen in the flame should never touch the work for that would burn it. When through welding, the operator should turn the oxygen off first. Theoretically, two parts of hydrogen should be used for each part of oxygen, but experience shows that it is desirable to use about three parts of hydrogen to one of oxygen. Some operators advocate using even more hydrogen, but this is not necessary when the gases are properly mixed before entering the flame.

Process of Oxy-Hydrogen Welding. The process of welding with oxy-hydrogen is similar to other hot-flame processes and the joints must be beveled in the same way to make them accessible for filling. The work should be heated first, in order to prevent chilling of the filling material, and the melt bar fused in to make the joint. Iron and the other industrial metals can be welded by this process; the cost is similar to that for work done by the oxy-acetylene process, although somewhat higher for most operations.

Time Required for Weld. The time required for welding seams in steel plates will vary from two minutes per foot on $\frac{1}{32}$-inch sheets up to five minutes on $\frac{1}{4}$-inch plates. It is claimed that the oxy-hydrogen flame does not affect the ductility of the metal like the oxy-acetylene flame.

MISCELLANEOUS GAS PROCESSES

BLAU-GAS WELDING

General Advantages. The advantages claimed for the blau-gas process are safeness, cheapness, compressibility of the gas to a liquid, high B. T. U. (1800 per cubic feet), and convenience. On the other hand, the oxy-blau gas flame is not so hot as the oxy-acetylene and must be larger to do the same work. This is sometimes a disadvantage. This system is well established in Europe; it has been used in this country only a few years and has not proved a very serious competitor of the other systems.

Equipment and Cylinders. The apparatus used for blau-gas welding consists of the regulation gas cylinders containing blau gas at 100 atmospheres pressure, cylinders with compressed oxygen, a gas expansion cylinder, pressure indicating and reducing gages, tubing, and high-pressure torches. Because the blau gas is composed of gases of different critical pressures, it must not be drawn from the top of the cylinders direct; so a tube extends through the liquid gas to the bottom of the cylinders and the heavier liquid is drawn off first. This expands in the expansion cylinder and blowpipe before entering the flame. The lighter gases are drawn off last. The customary glasses should be provided for the workmen's eyes.

Torch. The welding torch has several sizes of tips, and the cutting torch is so arranged that there is a preheating flame around the oxygen inlet. Liquid blau gas is first let into the expansion chamber at about 50 pounds pressure and then into the torch at from 10 to 20 pounds, according to the work to be done. The oxygen is led directly to the torch at pressures of 15 to 30 pounds for the various operations. Cutting requires higher pressures than welding.

Process of Blau-Gas Welding. The process of welding with the oxy-blau gas apparatus is similar to the other hot-flame systems, excepting that its heating value is less and a larger spread of flame is required to give the required amount of heat units and temperature for the work.

PINTSCH-GAS WELDING

The use of Pintsch gas and oxygen for hot-flame welding, the latest addition to the list of possible systems for general use, was

developed by the Safety Car Heating and Lighting Company, New York, primarily for use by steam railroads. It is as general in its applications as any of the other systems, and the fact that every railroad has Pintsch gas on its cars and supply stations at frequent intervals should result in a wide application in shops which have no electric-arc welding apparatus. The principal feature of this process, as with the other gas systems, seems to be a special torch, and the apparatus is similar to the others.

Equipment. The apparatus consists of the two steel cylinders for the gases, valves for regulating the pressure, tubes for the gas, and the special torch. The gas is furnished at a pressure of 100 atmospheres (about 1500 pounds) and the oxygen at 10 atmospheres (150 pounds). The gas can also be obtained at 180 pounds pressure. The high-pressure gas is reduced in two steps when used, the first being from 100 atmospheres to 14 atmospheres and then down to the 25 pounds to the square inch at the torch. Two gases are delivered through two tubes to a chamber at the back end of the torch and there mixed. A valve is provided in each inlet. The tip of the torch contains a preheater which operates by internal combustion and produces a high-temperature, non-oxidizing flame. This feature of the torch is valuable and adds to the temperature of the flame.

The process of welding with the oxy-Pintsch flame is the same as with the oxy-acetylene flame, but the manufacturers claim considerable saving in cost of operation. They give 3.4 cents as the cost of cutting one foot of an 18-inch channel $\frac{15}{32}$ inch thick, and the total cost of the work done on the channel 86.2 cents, against the old cost of $4.66 by drilling and chipping. No figures are available at this time for welding operations, but all sorts of articles can be successfully welded and cut by this process. The preparation of the joints should be the same as for other gases and the metal should be handled in the same way.

WATER-GAS WELDING

In water-gas welding oxygen is mixed with the gas and used as other gases. The gas is drawn from the mains and carried to the torch and there mixed with the oxygen. It can be obtained compressed into cylinders like the other gases. However, in view

of its low heating value and the gradual reduction in the cost of acetylene, it is not in general use.

Process of Welding. *Adjusting the Flame.* The process of welding with any of the gas flames is similar to that of using the graphite electrode in electric-arc welding, as the flame is the source of heat and the filling material is added as melted. It has the disadvantage of being somewhat dangerous on account of the open flame. The first thing the operator has to do is to learn how to adjust his flame, and this is not easy because there is no rule for the exact proportion of oxygen and acetylene. It is approximately 1 part acetylene to 1 part oxygen for most purposes. If the oxygen is as great as 2.5 against 1 of acetylene, an oxidizing flame will be produced which will probably cut the metal; if there is too much acetylene to be all consumed in the flame, it will split up and allow carbon to enter the weld and carbonize it. The flame should be so adjusted that the two cones formed in the flame unite to form a single small one. In operation, the tip of the white cone in the flame should just touch the metal and the hand should be held steady because, if the tip of the torch should touch the work, it will cause a flash back and necessitate relighting, if nothing worse. The torch should be given a sort of rotary motion around over the surface of the weld, with a slight forward and upward movement, in order to blend the metal and reduce the liability to overheat it.

Care for Expansion During Heating. All welding operations, whether with gas or electricity, should be undertaken only after a careful consideration of the effects of expansion and contraction on both the joint and the piece welded. This is especially important when welding castings.

Preheating. Cast-iron pieces and articles of circular or closed shapes, such as wheels, should be preheated before welding and reheated afterwards to relieve any stresses which may be set up in them. Gas furnaces or oil burners make good preheaters as they are much cheaper than the oxy-acetylene flame for heating preparatory to welding.

Conditions of Metal and Joint. It is important to have the surfaces clean before starting to weld. If the parts have been cut with the flame, they must be chipped off in order to remove the

oxidized material and prevent its being welded. Plates to be welded should be beveled on the edges, unless they are less than $\frac{1}{8}$ inch thick, and filling material of similar composition should be used for the joint.

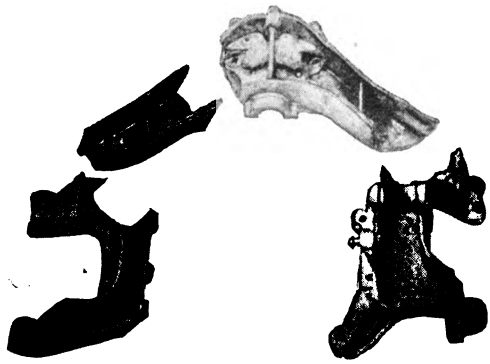


Fig. 68. Broken Aluminum Casting
Courtesy of Davis-Bournonville Company

The edges of the bevel should be from 30 to 45 degrees in angle and the plates should be spaced slightly apart to insure filling clear through the joint. The opening should flare a little from the end where work begins to the opposite end, in order to allow for the drawing together of the parts as the work progresses. Fluxes are an advantage in gas welding, as they absorb or reduce the oxide formed by the gas flame and prevent burning out of the carbon from the high carbon steels, etc.

Effects on Various Metals. *Aluminum* is very sensitive to oxygen, so an excess of acetylene in the flame is desirable when working on aluminum. The metal does not run readily and must be puddled into place with an iron rod. It has a low melting point, and is difficult to weld. After it is welded it is toughened by hammering. Figs. 68 and 69 show a successful piece of aluminum casting welding. *Brass* can be welded readily with a moderately large flame, but the cone of the flame should be kept away from the metal. Borax is used as a flux for brass and the

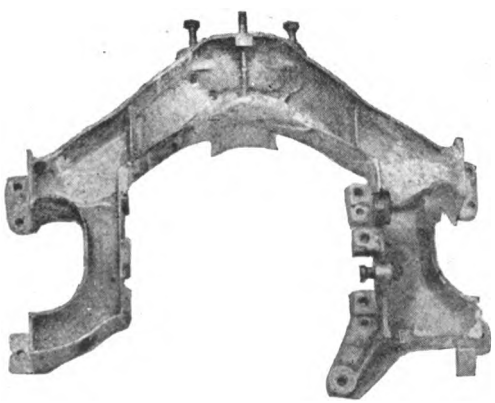


Fig. 69. Aluminum Casting Welded by Gas Torch
Courtesy of Davis-Bournonville Company

weld is usually not very strong because the material after being melted is merely cast brass. *Copper* should be welded with a low temperature flame and hammered afterwards to restore its toughness. It is well also to know that acetylene attacks copper and that care must be exercised to prevent an excess in the flame as this may form acetylide of copper, a fulminate which can be exploded by striking with a hammer or even by high friction.

Cast iron can be welded, but it is very apt to crack when cooling; therefore careful preheating is necessary before welding

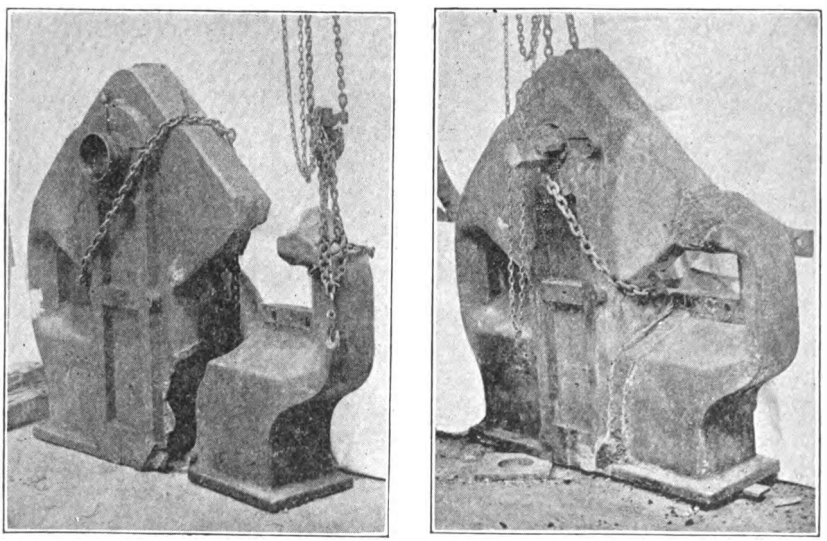


Fig. 70. Immense Shear Casting Broken and Welded by the Gas Torch
Courtesy of Davis-Bournonville Company

and slow cooling afterwards. High silicon cast-iron melt-bars, which are low in sulphur and phosphorus, are used, and borax forms a good flux. As cast iron runs freely, a mold should be made around the spot to be welded to retain it, and the work done horizontally. A successful weld of a big casting is shown in Fig. 70.

Wrought iron becomes cast iron when it cools—unless it is very low in carbon and silicon—and as it loses its structure it should be hammered to toughen it. It does not readily melt to a fluid but becomes a sort of thin paste and must be worked into place with the melt bar.

Steel, with a small percentage of carbon, welds more easily than high-carbon steel, and the carbon is likely to burn out or so change its structure near the weld as to destroy its essential properties. High-carbon steels require careful heat treatment after welding to restore their original properties, and soft steel should be hammered to toughen it. Steel may be welded to iron or copper by proper manipulation, but these are uncertain operations and are very seldom necessary. A repaired steel bolster is shown in Fig. 71.

Alloys of nearly all kinds may be welded with oxy-acetylene apparatus; the principal point to look out for is to be sure that the composition of the alloy is known before starting. If the flame is adjusted to suit the most sensitive metal and its action watched, there should be no serious trouble.

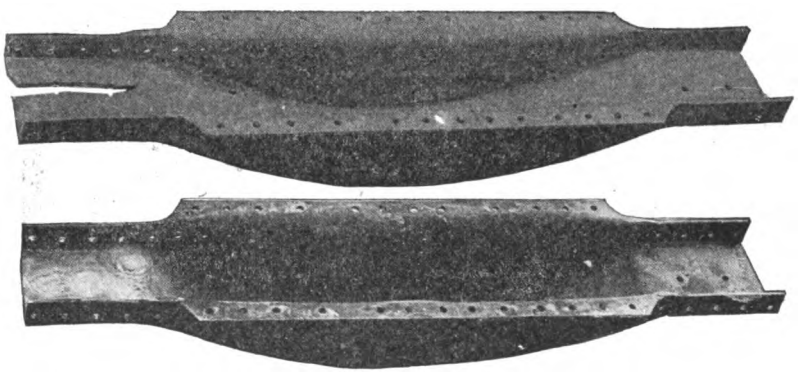


Fig. 71. Split Steel Bolster Welded by Gas Torch
Courtesy of Oxweld Acetylene Company

CUTTING WITH GASES

All the gases described for welding are used also for cutting, and they offer some advantages over other methods of cutting for various purposes. The work is done by heating the metal to about 1500 degrees Fahrenheit with a flame composed of oxygen and another gas and then directing a blast of oxygen against the heated surface. At that temperature iron and steel have a great affinity for oxygen; so the metal is oxidized or burned up so rapidly that a clean cut is made in the piece. The metal is entirely destroyed, of course, but the work is done so quickly and the slot cut is so narrow that it is considered no disadvantage.

The metal passes off in the form of an oxide. Pieces of almost any commercial thickness may be cut. Metallic blast-furnace tap holes have been cut out to depths of four feet.

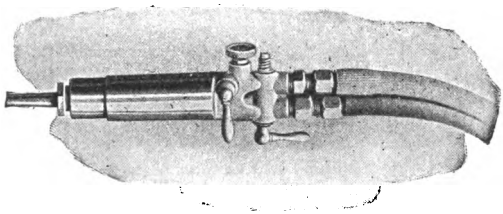


Fig. 72. Cutting Blowpipe
Courtesy of Davis-Bournonville Company

Equipment for Cutting. The apparatus required for cutting consists merely of a torch, Fig. 72, tubes for the gas and oxygen, and a source of supply of gases. The gases are generally supplied in tubes as in welding, and portable outfits are most convenient for all-around use. The torches used for cutting differ from those used for welding in that an extra stream of

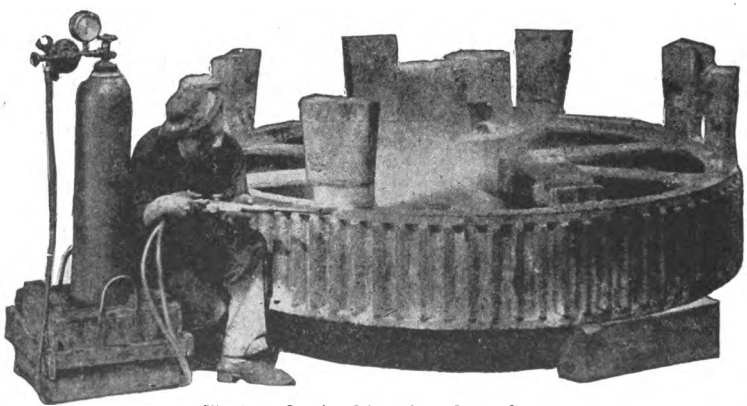


Fig. 73. Cutting Risers from Large Gear
Courtesy of Oxweld Acetylene Company

oxygen must be carried to the tip end. This is generally done by an extra tube along one side of the torch. In some forms the oxygen is then carried through the preheating flame, but the most efficient types

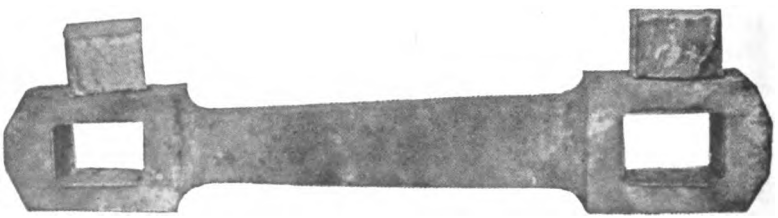


Fig. 74. Crosshead Slots Cut Out of Drop Forging
Courtesy of Oxweld Acetylene Company

are those in which the oxygen is brought into contact with the metal just back of the main flame and so directed as to cause the oxygen to strike the hot spot. The composition or hardness of the metal have no apparent effect on the speed of cutting. Chrome nickel steel armor plates nine inches thick can be cut at the rate of $2\frac{1}{4}$ minutes per foot of cut, with oxy-hydrogen flames. Figs. 73 and 74 show heavy pieces which have been cut with hot-flame apparatus. Numerous cutting machines have been devised for automatic work, among which are those for holes, rails, cams,

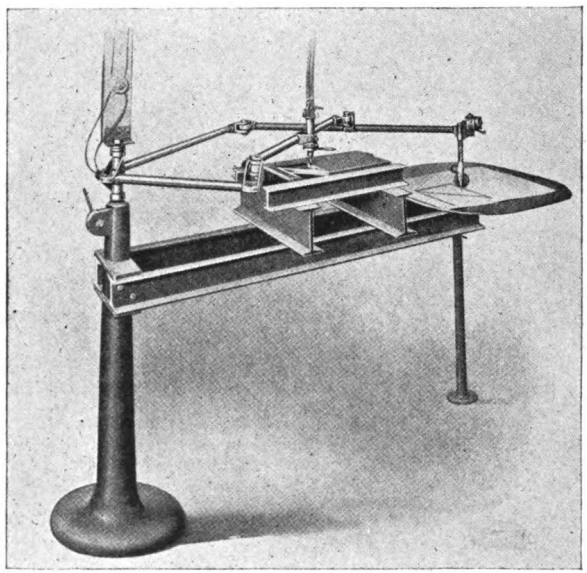


Fig. 75. Oxygraph for Cutting Steel According to Pattern with Oxy-Acetylene Flame
Courtesy of Davis-Bournonville Company

irregular curves, and straight lines, Fig. 75, and they are much more rapid and efficient than hand cutting because of their uniform feed and speed. For work on which they can be used they are a good investment.

Applications of Hot-Flame Cutting. The applications of hot-flame cutting are so numerous that only a few of them need be described in order to give a good general idea of its possibilities. The accompanying examples were done with oxy-acetylene, oxy-hydrogen, and other gases, and the work is very similar with all

of them. The principal characteristic of the work done is the smoothness of the cut, and the cost compares very favorably with that of cutting with the electric arc. It is cheaper than the arc on moderate and small work but more expensive on large work. The low first cost of the outfit makes it appeal to small shops and scrap dealers; it is very valuable for cutting up junk and all sorts of wreckage. The battleship *Maine* was dismantled with an

Fig. 76. Cutting up the *Maine* with Gas Blowpipe
Courtesy of Oxweld Acetylene Company

Oxweld acetylene outfit, Fig. 76, and the ruins of the Quebec bridge were also cut away with this apparatus, Fig. 77. Manholes in tanks and boilers, portholes in steel vessels, ruins of burned or wrecked buildings, and, in fact, almost anything of metal may be cut rapidly and conveniently by this process. It is not necessary to have the article in any particular position, as the work may be done wherever the operator can carry his torch. Work has been done on the top of high towers and stacks, in

deep holes, in steam vessels, inside locomotives, and on the under side of bridges.

Cost of Hot-Flame Cutting. The cost of cutting will depend upon the cost of the gases, cost of labor, the nature of the work, and the facilities for handling it, but a few typical jobs will give a good idea of the possibilities. The accompanying connecting rod forging for a stationary engine is 6 inches thick and the crosshead slots are each $9\frac{1}{2}$ inches by 7 inches in size and were cut out in 15

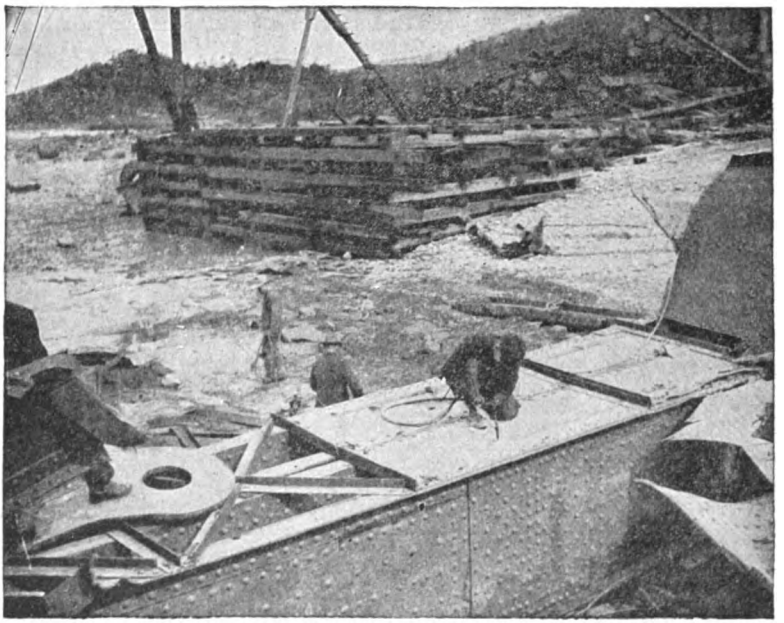


Fig. 77. Cutting up Ruins of Quebec Bridge with Acetylene Blowpipe
Courtesy of Oxweld Acetylene Company

minutes each. The total cost of the operations was $6.00, including labor and gas; the usual method of drilling and chipping would have taken 8 hours for each slot and have cost more. In steel and iron foundries this system is used for cutting off risers and gates from the castings and, in boiler shops, for cutting plates of considerable thickness, cutting off rivet heads, cutting holes, etc. The 4×6 foot plate, $\frac{9}{16}$ inch thick, shown in one of the illustrations, is a cross brace plate for a locomotive frame, which was cut as shown in one hour. The total amount of cutting was 264

TABLE XV

Cost of Cutting per Foot of Cutting Length

Thickness of iron in inches	⅛ in.	¼ in.	5/16 in.	⅜ in.	½ in.	⅝ in.	¾ in.	1 in.	1¼ in.	1½ in.	2 in.
Consumption of oxygen in cubic feet per foot of cutting length	0.45	0.50	0.60	0.80	1.30	1.90	2.50	3.10	4.00	5.60	7.60
Consumption of acetylene in cubic feet per foot of cutting length	0.12	0.13	0.13	0.18	0.19	0.21	0.25	0.30	0.36	0.41	0.47
Length of time in minutes per foot of cutting length	1	1	1	1¼	1¼	1⅓	1⅓	1⅓	1½	1½	1¾
Total cost in cents per foot of cutting length	1.25	1.35	1.5	2.1	2.7	3.7	4.6	5.7	7	9.5	12.75
Thickness of iron in inches	2½ in.	3 in.	4 in.	5 in.	6 in.	7 in.	8 in.	9 in.	10 in.	11 in.	12 in.
Consumption of oxygen in cubic feet per foot of cutting length	8.25	11.80	15.30	20.60	26.00	32.00	37.00	44.00	51.00	59.00	68.00
Consumption of acetylene in cubic feet per foot of cutting length	0.60	0.90	1.20	1.40	1.65	1.90	2.10	2.35	2.70	3.10	3.25
Length of time in minutes per foot of cutting length	2	2½	3	3	3½	4	4	5	5	5½	6
Total cost in cents per foot of cutting length	14.5	20	25	34	42	52	59	71	82	95	108

This table is based on a price of $1.50 for 100 cubic feet of oxygen, of 3½ cents per lb. for the calcium carbide and on an expense for wages of 35 cents per hour. The figures relating to the consumption of material are but approximate and are supposed to be for straight cutting. The necessary proficiency and experience can be acquired in a few days.

lineal inches; the rate was $3\frac{3}{4}$ minutes per running foot. Where articles are to be welded after cutting, it is necessary to remove the oxidized surface from the cut before welding. This can be done with a pneumatic chisel.

The cost of cutting steel pieces, per foot of length, using the oxy-acetylene flame is given in Table XV (prepared by Messer and Company, Philadelphia) and is approximately correct for other systems.

THERMIT WELDING

Welding by the thermit process is really "cast welding," because it is accomplished by pouring "thermit steel" around the parts to be joined. The main difference between this and other methods of cast welding lies in the method of producing the molten metal. The name for the process is derived from the Greek word *therme*, meaning "heat," and signifies that it is a heat process of welding. The name was originally adopted as a sort of trademark but has come to be accepted as the name of the process.

Chemical Reactions in Thermit Welding. The thermit welding process is based upon a long series of experiments carried on for a number of years by various physicists and metallurgists to find some method of reducing metals readily from their oxides and ores. It is the direct result of the work done by Dr. Goldschmidt, of Essen, Germany, in what is now the new field of aluminothermics, and is based on his discovery that if finely divided metallic oxides are mixed in certain proportions with finely divided aluminum they will, if ignited, fuse and produce a temperature of 5400 degrees Fahrenheit in less than 30 seconds without the use of heat or power from the outside. The high affinity of aluminum for oxygen will cause it to draw the oxygen from the metallic oxide, combine with it to form aluminum oxide, raise the temperature of the mass by the violent reaction, and set the metal free. The greater weight of the metal will cause it to flow down through the mass in the container and the aluminum slag will rise to the top.

For ordinary commercial welding purposes in machine shops and foundries, iron oxide is used and the reaction takes place according to the equation

$$Fe_2O_3 + 2Al = 2Fe + Al_2O_3$$

The liquid steel produced by this process represents one-third of the original material by volume and one-half of the original mixture by weight, the balance being lost as slag. This method of cast welding was developed about the year 1900. The peculiar reaction used has also been applied to the production of numerous kinds of alloys and metals free from carbon. Further reference will be made to this.

Analysis of the Composition of Thermit Steel. According to data furnished by the makers of thermit welding apparatus the average analysis of thermit steel is as follows:

Carbon	0.05 to 0.10
Manganese	0.08 to 0.10
Silicon	0.09 to 0.20
Sulphur	0.03 to 0.04
Phosphorus	0.04 to 0.05
Aluminum	0.07 to 0.18
	0.36 to 0.67

The rest of the mixture is iron.

Method of Starting the Reaction. During the experiments leading to the development of thermit welding, the mixture of metallic oxide and aluminum was heated from the outside to start the reaction, but since finely divided aluminum will not melt at the temperature of cast iron it was necessary to heat the mass so high that when action started it resulted in an explosion. So Dr. Goldschmidt used a storm match to ignite a fuse of barium peroxide (BaO), which in turn ignited the mixture and started the reaction.

Equipment for the Process. The apparatus required for thermit welding consists of a crucible, tripod, preheater, yellow wax, and a spade, with which there must also be used perishable materials consisting of thermit, manganese, molding material, and ignition powder. The shell of the crucible is of sheet iron, and it is lined with magnesia in order to stand the high temperature. It has a magnesia stone thimble at the bottom, through which the metal flows. The process of preparing the lining is rather elaborate and must be carefully handled, or the life of the crucible will be shortened. A tripod is used to support the crucible above the work. The preheater is a combination compressed-air and gasoline outfit used to heat the article to be welded in order that it

may not chill the filling material. The wax is used as a pattern of the space to be filled when welding, and about this a mold is made. It is melted out of the mold before the welding begins.

Preparing the Mold. The process of preparing the crucible and the mold are the principal features of the entire operation of thermit welding, as the mere act of casting the weld is comparatively simple. The crucible, which is shown in Fig. 78, suspended above the mold, is a sheet-iron shell with a hole in the bottom for

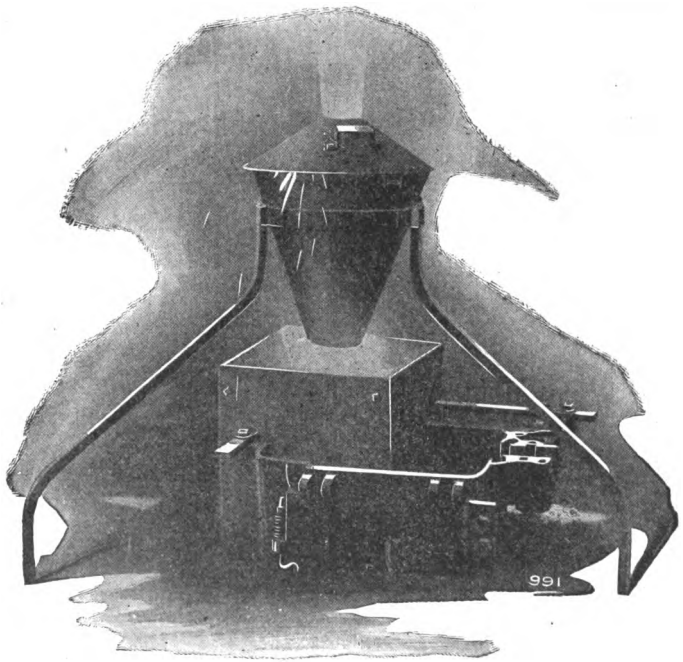


Fig. 78. Thermit Crucible Pouring Charge into Mold
Courtesy of Goldschmidt Thermit Company

the metal to pass through. A lining of magnesia, carefully packed while hot enough to be plastic, is prepared, and a magnesia stone thimble put at the bottom to form a bushed hole and protect the crucible. The magnesia lining should be put into place slowly and carefully and tamped tightly into place, for its value depends largely upon how hard it is packed. The lining is formed around a matrix to shape the hopper-like center and must be baked at a dull red heat for six hours before it is ready to use. A crucible will withstand about 20 reactions if well made, and must then be

relined. The thimble must be placed in the bottom of the crucible so as to be removable.

Construction of Mold. The construction of the mold is really the most important part of the operation, because upon this depends the amount and application of the filling material. The container or flask is usually made of steel plates placed so as to form a box around the part to be welded, and then filled with the clay, etc., of the mold, the plates being fastened with bolts, tie-rods, clips, or clamps of whatever sort may be available, Fig. 79. The first step in the formation of the mold is to build a collar of the yellow beeswax around the place to be welded, making this of the size and shape desired for the weld. After the collar is

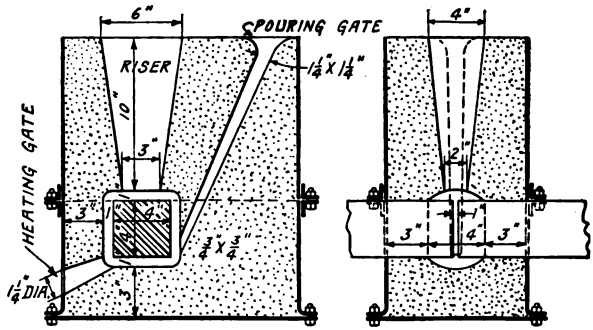


Fig. 79. Section of Typical Thermit Mold Showing Riser, Pouring Gate, and Heating Gate
Courtesy of Goldschmidt Thermit Company

formed, the flask is placed around it and filled with a mixture of ground fire brick, fire clay, and fire sand in equal parts. There must be three channels in every mold—a pouring gate, a riser, and a heating gate. The pouring gate should run from the top of the mold down to the bottom of the wax collar to insure the metal filling the mold and to allow the good steel to reach the weld instead of being crowded out by the slag. The riser should be immediately above the wax collar, if possible, so that the slag and surplus metal can rise freely from the metal of the weld, and the heating gate should run from one side of the mold into the bottom of the collar in order that the wax can all run out of the mold when melted by the preheating torch. As soon as the mold is completed, the torch is applied and the wax melted out,

Fig. 80. The flame is allowed to play into the mold until the latter is entirely dry and then the heating gate must be plugged with clay to stop it up entirely. Fig. 81 shows a typical thermit weld, with pouring gate and riser still attached.

Thermit Required. The amount of thermit required to make a given weld will be twice the amount necessary to fill the space formed by the wax collar, because one-half of the weight of the original powder will rise in the form of aluminum slag, as already

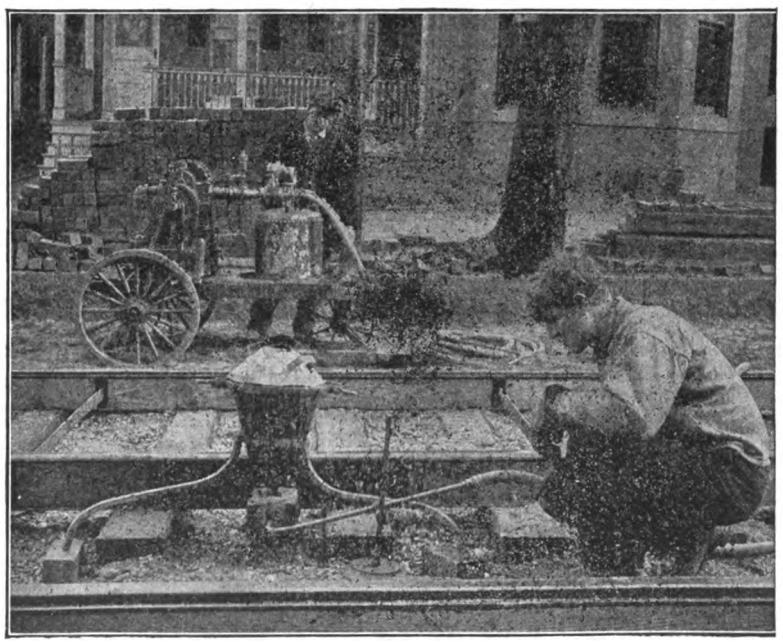


Fig. 80. Preheating Steel Rail Prior to Forming Weld
Courtesy of Goldschmidt Thermit Company

stated. On the other hand, the cubical area of riser and gate must be twice as great as the collar because the volume of the slag will be two-thirds of the total volume of the casting. It has been determined by experience that the weight of thermit necessary for a given job will be 32 times the weight of the wax required to form the collar for the mold; so the wax should be weighed after melting out of the mold in order to know how much thermit is required for the job. The size and shape of the mold and riser and gate will vary somewhat for different jobs and the

relation between weight of wax and mixture will vary accordingly, but the ratio of 32 to 1 is a good average. It is necessary to preheat the article at the joint until it is red-hot before starting to pour the metal, and this is done with the gasoline torch through the heating gate at the bottom of the mold before it is plugged.

Addition of Other Materials. When more than 10 pounds of thermit are required for the weld, it is necessary to moderate the heat of the reaction slightly, and this is done by adding small pieces of clean steel to the powder. These may be punchings, rivets, or any other soft steel pieces, but they must be free from

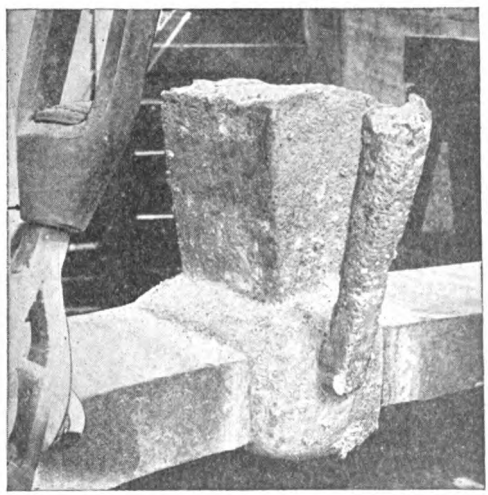


Fig. 81. Typical Thermit Weld Showing Riser and Pouring Gate Casting Still Attached
Courtesy of Goldschmidt Thermit Company

grease, for carbon must be kept out of the mixture. From 10 to 15 per cent of the weight of the thermit may be added in this way. About two per cent of pure metallic manganese should also be added in order to increase the strength of the weld. If the manganese is not obtainable, three per cent of ferromanganese may be added instead, although this increases the violence of the reaction and hardens the metal.

Strength of the Weld. The average tensile strength of the welds made with thermit are 30 tons per square inch of cross section; and, if the joint is properly made, it will be hard to see

where it is. If a reinforcement can be left around the weld, it will give a higher strength than the original material, but where the weld is machined off, the strength will average 80 per cent of that of the piece welded, unless it be of unusually high tensile strength. When preparing the joint for welding, it is best to leave an open-

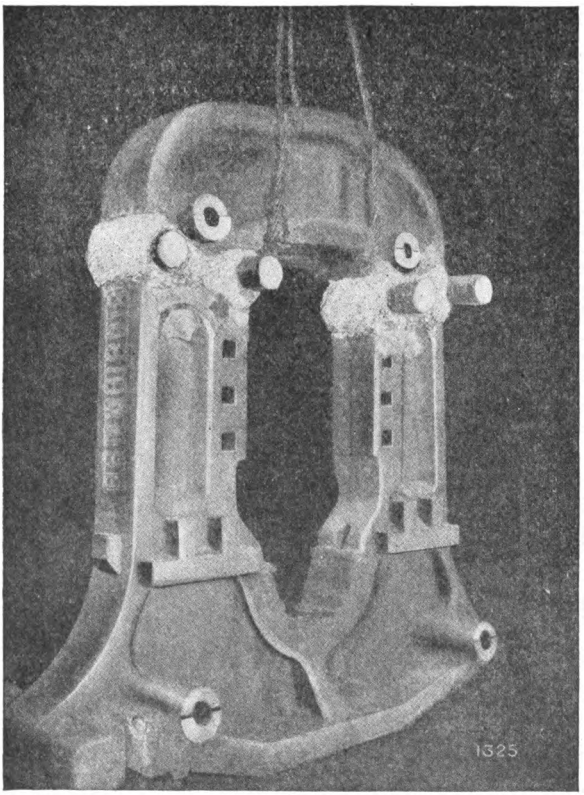


Fig. 82. Rolling Mill Housing Welded by Thermit Process
Courtesy of Goldschmidt Thermit Company

ing for the metal to flow into, and this should be at least $\frac{3}{4}$ inch wide, preferably more.

Applications of Thermit Welding. The applications of thermit welding are numerous, although the process is better suited to large jobs where the saving in cost of new pieces will justify the cost of the work, Fig. 82. It will be evident also that the process lends itself better to welding large articles than small ones, and

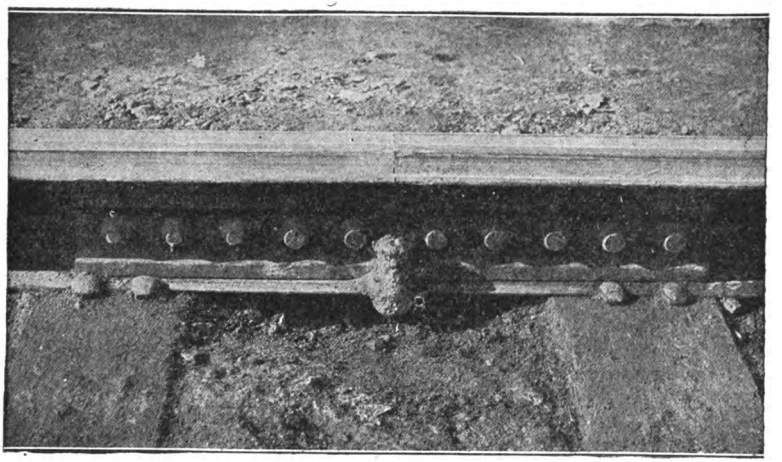


Fig. 83. Rails Welded by Thermit Process
Courtesy of Goldschmidt Thermit Company

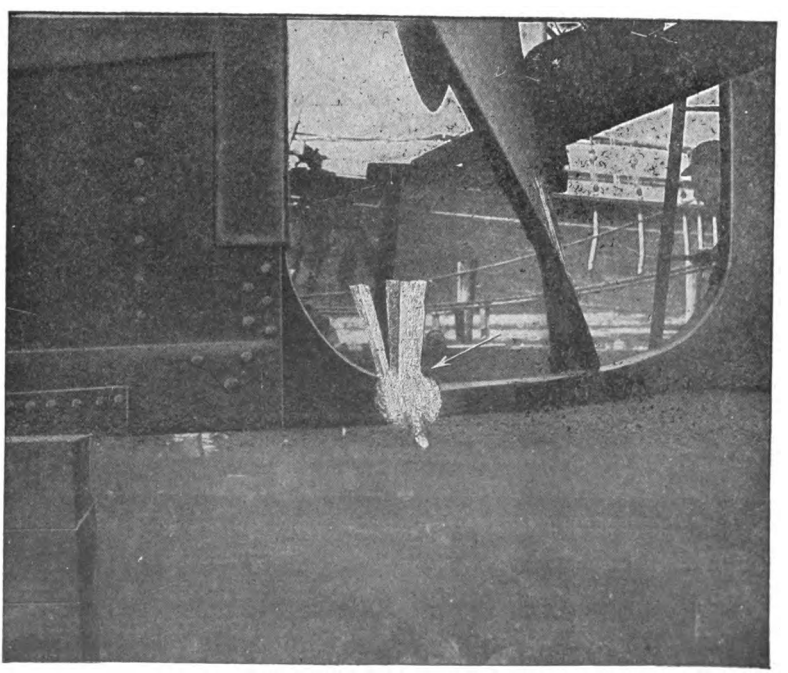


Fig. 84. Broken Stern Post of Boat Welded by Thermit Process
Courtesy of Goldschmidt Thermit Company

experience up to the present shows that most thermit welding has been done on such large articles as engine and machine tool frames, locomotive side frames, and motor cases. Fig. 83 shows a typical

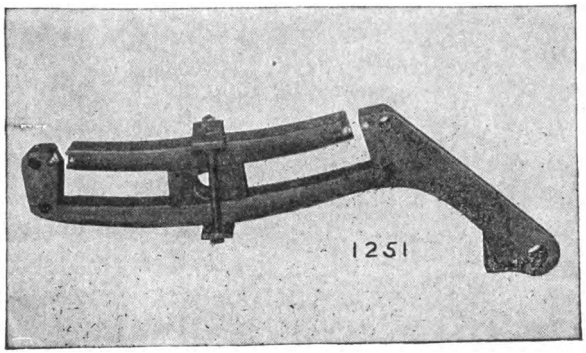


Fig. 85. Broken Locomotive Link Ready for the Molds
Courtesy of Goldschmidt Thermit Company

thermit weld at a rail joint. This is a modified Clark joint. Another useful application of the method is in welding stern posts and rudder posts of vessels, Fig. 84. The widest application seems to be in steam railroad shops; and, while it is true that the electric arc-welding process is rapidly superseding all others for that service, some of the work done is worthy of description. Considerable saving has been made by doing the work without dismantling the

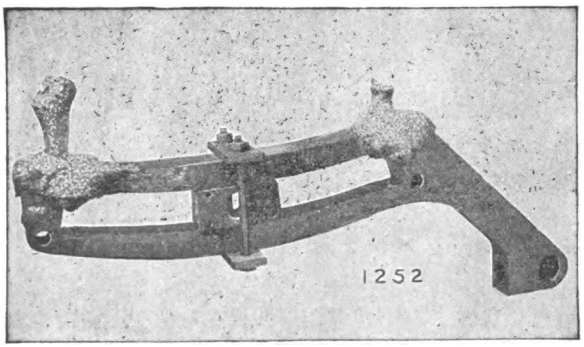


Fig. 86. Welded Locomotive Link with Molds Removed
Courtesy of Goldschmidt Thermit Company

engines in order to get at the break. The process is to form the mold about the break, as described, and set the crucible above it ready for pouring. Where it is possible to lay the article on the

floor, as when welding crank shafts or a broken link, Figs. 85 and 86, the job is much easier and quicker to perform.

The break, if in the upper part of a locomotive frame, for example, should be cut out about an inch and the frame jacked apart $\frac{1}{4}$ of an inch. The inch space allows for filling, and the $\frac{1}{4}$ inch for shrinkage; so the jacks should be removed as soon as the mold is filled. Breaks in other parts of locomotive frames are treated in the same way. For welding driving-wheel spokes, it is best to heat the adjacent spokes with a torch to expand them before welding the broken ones, and then allow them all to cool as soon as the welding is done. Rail welding for street railways, another application of thermit, is clearly shown by the accompanying illustrations. In all cases it is necessary to clean the metal thoroughly around the joint to remove grease and scale. This is best done with a sand blast, which insures bright clean metal to fill against. For work of this nature it pays to provide the fullest equipment in order that there may be no failures, because the operation is very expensive and very hard to do over again.

Use of Thermit in Other Processes. *Foundry Work.* Other uses of thermit are in foundries for improving the quality of the castings and in metallurgical work to produce metals and alloys free from carbon. In foundries it has been found that, by placing a can of thermit in the ladle before pouring, the temperature of the metal will be raised and, by using thermit of the proper composition, the strength of the metal can be increased or its composition varied to suit different jobs. It is also used in steel mills to reduce losses from "piping" of the ingots. A "pipe" is a hole formed in the top of the ingot when cooling, due to shrinkage and the presence of slag. It may extend a considerable distance down into the ingot and reduce its value for rolling. So a can of thermit is thrust down into the top of the ingot at a certain point in the cooling, and this ignites and fuses the steel down and forces the slag out. The mold can then be filled the rest of the way with good steel.

Producing Alloys. The use of thermit, for the production of alloys, etc., has been successful with such metals as titanium, chromium, manganese, vanadium, etc., and alloys of the following compositions have been made:

Ferrotitanium	20–25% Ti.
Chromium	97–98% Cr.
Chromium Manganese	30–70 parts
Chromium Copper	10% Cr.
Chromium Molybdenum	50–50 parts
Manganese	97–98% Mn.
Manganese Copper	30–70 parts
Manganese Titanium	30–35% Ti.
Manganese Tin	50–50 parts
Manganese Zinc	20–80 parts
Manganese Boron	30–35% Bo.
Ferrovanadium	30–35% Va.
Ferromolybdenum	50–50 parts
Ferroboron	20–25% Bo.

Ferrotitanium is used as a purifying agent for steel; chromium is used as an alloy with steel to produce crucible steel, etc.; manganese is used to produce very hard steel, bronze alloys, etc.; molybdenum is used in making tool steels; vanadium is used to add to the strength of iron and steel.

MISCELLANEOUS PROCESSES

SMITH WELDING OR FORGING

Smith welding is the process of joining metals by laying the pieces together and hammering at the place of contact until they become one piece. Most metals must be heated nearly to the temperature at which they begin to flow, before they can be welded. For iron and steel this is at the white heat; therefore it will be well to consider the action of the fire and the equipment required before taking up the study of the process in detail.

Producing the Proper Temperature. The combustion of fuel, either coal, coke, oil, or charcoal, causes the oxygen of the air to combine with the carbon of the fuel, and this chemical combination is what produces the heat. The *amount* of heat produced depends upon the amount of carbon and oxygen combined during combustion; whereas, the *temperature* attained depends entirely upon the rapidity with which the combination takes place. This is one of the most important facts to be learned in connection with welding, because the principle involved applies to all the other systems of welding as well as to smith welding.

Forced Draft. Ordinarily, combustion would not be rapid enough to generate the amount of heat required for welding; so a

draft is created through the fire in order to supply enough oxygen to the fuel and increase the rate of combustion. Too much air will chill the fire or blow it out, and an excess of oxygen will cause some of it to combine with the iron and form a scale of oxide of iron. This is called an "oxidizing fire"; whereas, if the oxygen is all consumed in the fire and there is an excess of carbon, it is then called a "reducing fire."

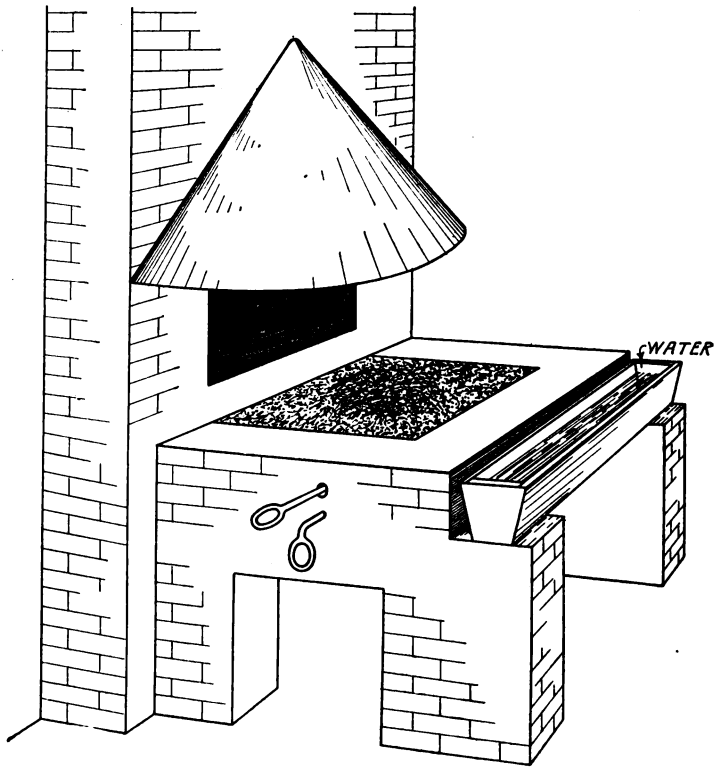


Fig. 87. Brick Blacksmithing Forge

Fuels. Coal, coke, charcoal, oil, and gas are all used as fuels for forges, but charcoal is the best because it is almost free from impurities. Coal and coke are good unless they contain sulphur and phosphorus. Sulphur makes iron "hot-short," or brittle when hot, and phosphorus makes it "cold-short," or brittle when cold. Copper, lead, tin, and other non-ferrous metals should be kept out of the forge, as they will spoil iron for welding.

Forges. Forges are of various kinds, usually of brick or iron, Figs. 87, 88, and 89, and consist primarily of a bowl with an air inlet or "tuyere" in the center of the bottom, a hood overhead to carry smoke and fumes to the chimney, a blower or bellows to supply air, an ash pit, and a trough or other vessel for water.

Forging Tools. *Anvil.* An anvil is required to provide a surface upon which to lay the pieces, when hammering to make the weld. It may be of cast steel or of wrought iron with a steel face, and usually weighs from 150 to 200 pounds. The anvil

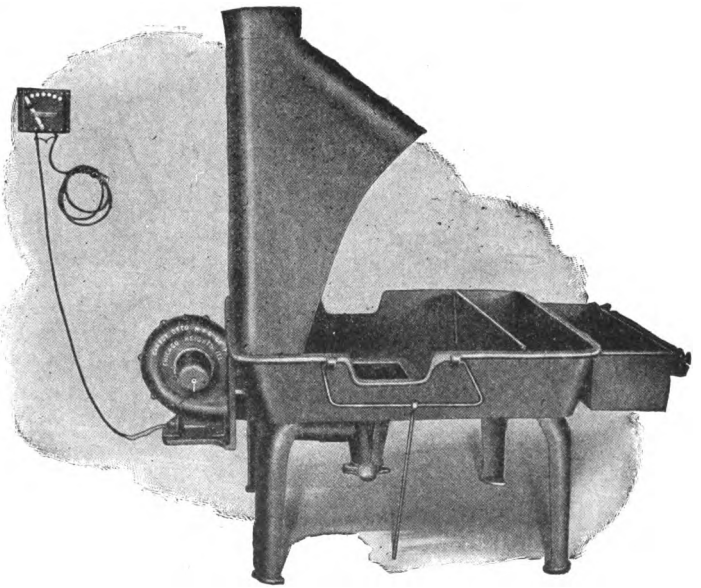


Fig. 88. Modern Motor-Driven Forge
Courtesy of Canedy-Otto Company

should be placed on a block of hard wood, Fig. 90, and securely fastened to it, and the height should be such that a man's knuckles will just reach to the top of it when he stands alongside.

Hammers. Hammers and sledges of various sizes and styles are required. Hand hammers, Figs. 91 to 94, weigh from 1 to $2\frac{1}{2}$ pounds and have handles from 14 to 16 inches long. Hand sledges, Fig. 95, weigh from 5 to 8 pounds and have handles from 24 to 30 inches in length. They are handled by a helper. Swing sledges, Fig. 96, weigh from 8 to 20 pounds and have 36-inch handles.

In addition to the foregoing hammers for general use, there are various kinds for special purposes. These include "set" hammers of various shapes, for forming the iron. Square set hammers, Fig. 97, are for producing flat surfaces; flatters, Fig. 98, are for similar use, but they cover a wider area; fullers, Fig. 99, are for spreading out the iron, hollowing out work, and forming shoulders; swages, Fig. 100, which are of numerous sizes, are for rounding pieces of iron; punches, Figs. 101 and 102, which are square or round, are for making holes; and cutters, Figs. 103 and 104, are hammers, with chisel-like edges on the top of the head, for cutting bars.

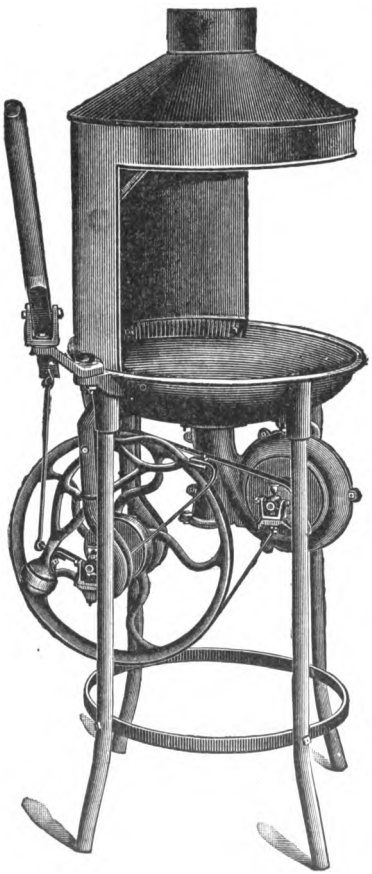


Fig. 89. Portable Hand Forge
Courtesy of Canedy-Otto Company

Anvil Tools. Anvil tools with stems to fit the square "hardie" hole in the anvil are made in shapes to match the set hammers previously described. They include fullers, swages, hardies, heading tools, etc., Figs. 105 and 106.

Tongs. Tongs are of many kinds and special ones are easily made. Flat tongs, Fig. 107, are used for flat iron bars, strips or plates. Pick-up tongs, Fig. 108, have curved springy jaws and are used for handling small pieces. Bolt tongs, Fig. 109, have a sort of pocket in the head or jaws for holding bolts while forming them. Gad tongs, Fig. 110, are shaped somewhat like bolt tongs.

Tongs soon become spoiled by the constant dipping in water and they bend out of shape easily while hot. They should not be left in the fire unless this is necessary, and should be kept in a rack when not in use.

Miscellaneous Equipment. In addition to the foregoing essential equipment, smith shops frequently contain many other tools such as dies, swage blocks, vises, surface plates, gages, taps, dies, calipers, Figs. 111 and 112, etc. For handling the fire there should be provided a poker, fire hook, shovel, sprinkler, and ladle, Figs. 113 and 114. A monkey wrench, chisel, and a pair of "C" clamps are also useful, and a tapered mandrel will be needed if rings are to be welded. A large portion of the equipment here mentioned will also be required for welding by any other method. A well-equipped shop is generally a good investment; on the other hand, it is usually better to start with the smallest equipment which will do the general run of the work and then buy special tools and equipment which experience shows to be necessary.

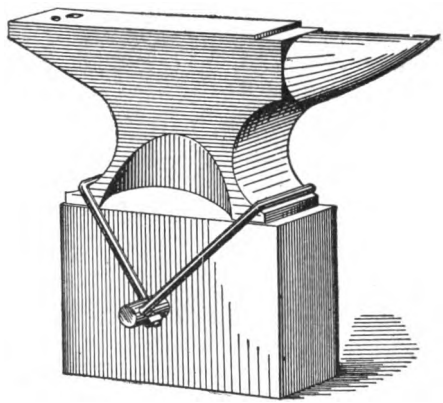


Fig. 90. Anvil Fastened to Block

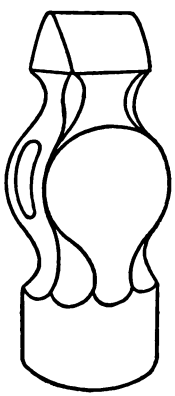


Fig. 91. Straight-Peen Hammer

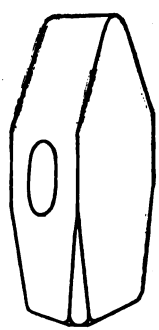


Fig. 92. Long-Peen Hammer

Fig. 93. Ball-Peen Hammer

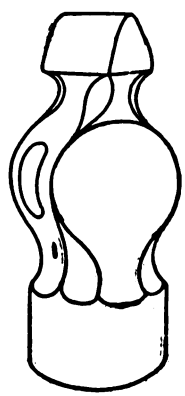


Fig. 94. Cross-Peen Hammer

General Features of Smith Welding. The process of smith welding, or forging, is comparatively easy to learn, but skill and the ability to use the process successfully will only come after long practice. The first operation to learn is to heat the iron

properly; this is done by placing it in the fire until it reaches a bright red, almost white, color. Large pieces will take longer to heat, and will remain hot longer, than small ones and the surface will tend to oxidize and flake off upon exposure to the air while hot. For ordinary forging operations this is no disadvantage beyond reducing

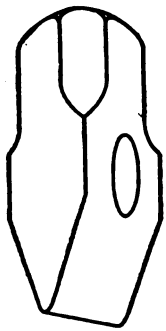


Fig. 95. Hand Sledge

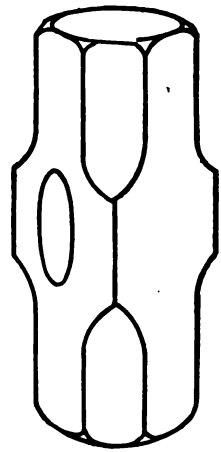


Fig. 96. Swing Sledge

the size of the piece slightly, but when welding two pieces together this oxide must be kept off by the use of a good flux, otherwise it will destroy the value of the weld by preventing cohesion of the particles forming the pieces. The most common flux for iron is clean sharp sand, which fuses and sticks to the surface and keeps out the air. Work can be done without a flux, if it is done

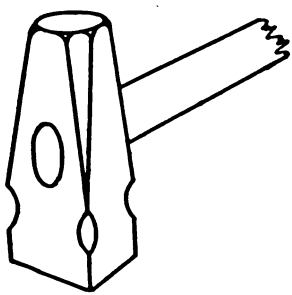


Fig. 97. Square Set Hammer

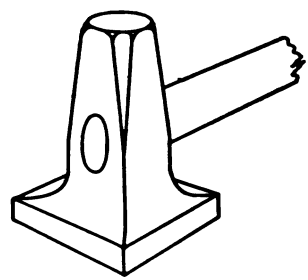


Fig. 98. Flatter

quickly. For steel, it is better to use potter's clay, wet with strong brine and then dried and powdered. Borax is sometimes used but it is not good for the metal.

Simpler Operations Performed First. The simpler operations of forging should be learned first and then the welding tried afterwards. "Drawing" is the operation of stretching the iron in one or two directions and hammering the hot piece —on all sides for lengthening, or on one side for flattening or spreading. If the piece tends to curl, it can be hammered on both sides to keep it flat. Square pieces should be turned over and over and hammered on all sides in drawing, and round ones should be hammered on all sides. "Upsetting" is the operation of increasing the diameter or thickness of a piece by heating and then hammering it on the ends until it becomes shorter through the flowing of the metal to the heated portion.

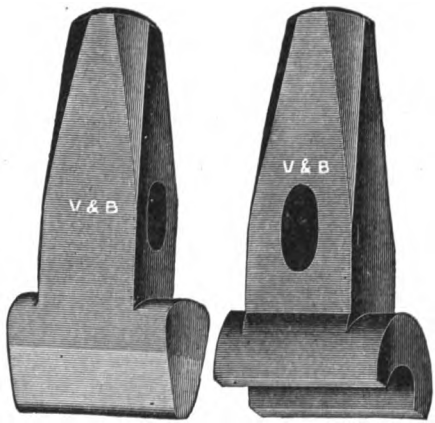
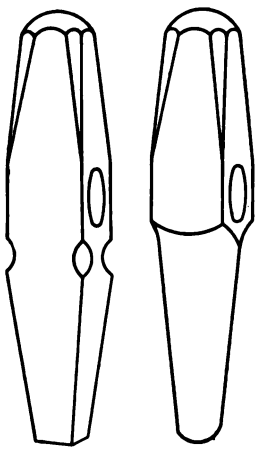
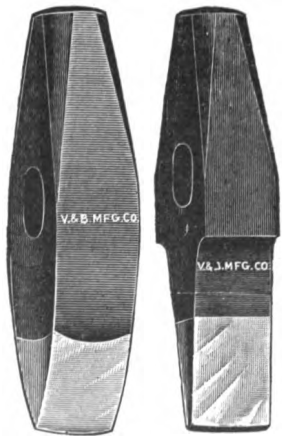


Fig. 99. Fuller Fig. 100. Swage
Courtesy of Vaughan and Bushnell Manufacturing Company



Figs. 101 and 102. Square and Round Punches



Figs. 103 and 104. Cold and Hot Cutters
Courtesy of Vaughan and Bushnell Manufacturing Company

The bar usually tends to bend under this operation; so it should be straightened at once by hammering on the high side. Considera-

ble heat is required for upsetting, and the fibers tend to separate or split apart when the piece is hammered lengthwise of its grain; so it is well to finish the upsetting by heating the second time and hammering all around to weld the fibers again. Bolt heads

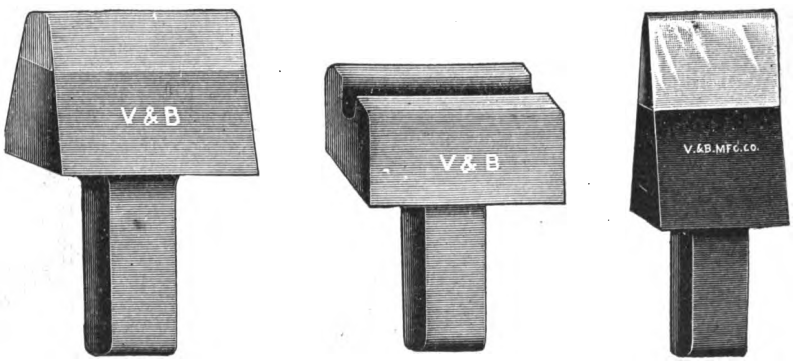


Fig. 105. Bottom Fuller and Swage and Hot Hardie
Courtesy of Vaughan and Bushnell Manufacturing Company

Fig. 106. Heading Tool

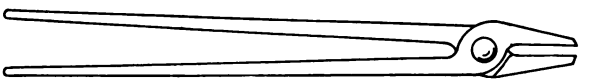


Fig. 107. Flat Tongs

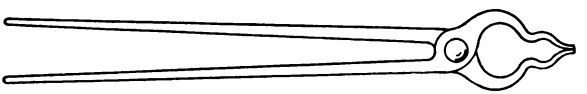


Fig. 108. Pick-Up Tongs

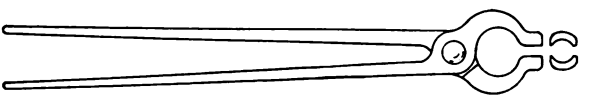


Fig. 109. Bolt Tongs

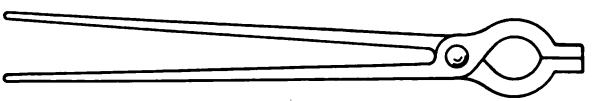


Fig. 110. Gad Tongs

are formed by upsetting the bar on the end and hammering square, or hexagonal, as required.

When forming corners which must be square, the pieces must first be upset to get enough stock and, when making connecting rod straps, crank shafts, rocker arms, hook eyes, eyebolts,

axe heads, armature shafts, and other articles of variable thicknesses, it is customary to upset them from straight bars before beginning to shape them. After the student has practiced the more elementary operations described and become familiar with his tools and his metal, he can then try welding.

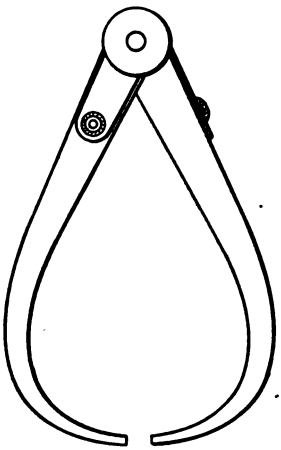


Fig. 111. Outside Calipers

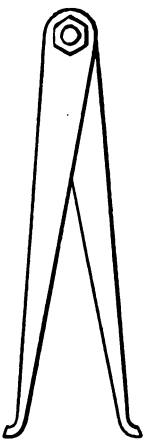


Fig. 112. Inside Calipers

Smith-welded Joints. Several kinds of joints are made by smith welding, the scarf weld, butt weld, lap weld, and cleft weld.

Scarf Weld. The scarf weld, Fig. 115, is made by "scarfing," or thinning the pieces at the end in order to give them a bevel. The iron should be upset a little to give enough extra stock to allow for the drawing down when hammering. The pieces should be rounded slightly on the surfaces which come together in order to allow the scale and slag to squeeze out and then they should be hammered while at a white heat. When they are thoroughly joined, the piece should be shaped all around by turning it while hammering.

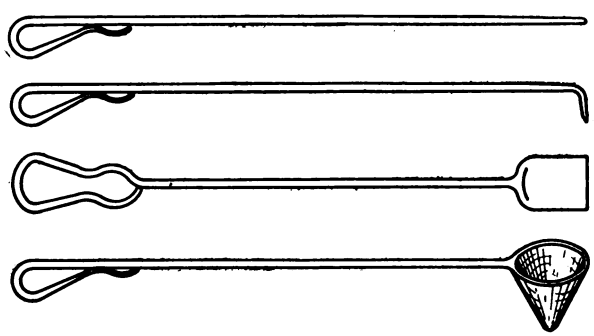


Fig. 113. Types of Fire Handling Tools

Butt Weld. The butt weld is made by hammering the pieces end to end until they unite, instead of uniting them by pressure,

as in the case of electro butt welding, the pieces being rounded slightly on the ends, Fig. 116, to allow the scale to come out. The operation tends to upset the pieces, and they should be drawn down to size again after welding. This sort of joint is not so strong as a good scarfed joint.

Lap Weld. The lap weld, Fig. 117, is made by simply laying one piece on top of the other, heating and hammering them until they unite, instead of pressing them under rolls as in electric welding. Work should start at the center and proceed toward the outside in order to force out the slag; otherwise the metal will not unite. It is not necessary to round up the parts for this joint, but a better job is insured if they are rounded.

Cleft Weld. A cleft weld, Fig. 118, makes the strongest joint. One piece is split at the end; the other is tapered and slipped into the fork of the first. Hammering the sides of the cleft together makes the pieces unite. The pieces should be first hammered on the ends in order to drive them tight together in the cleft, and it is good to round the sides of both pieces on the welding surfaces to allow slag to flow out.

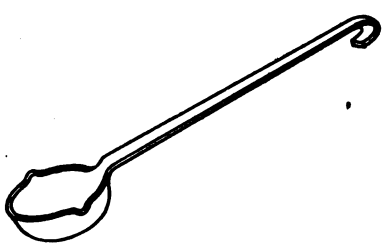


Fig. 114. Ladle

Applications of Smith Welding. The applications of smith welding are numerous, but a few of them will serve to give an idea of the possibilities. Scarf welds are used to form the corners of frame work made of flat bars, Fig. 119. One piece is beveled on the end and the other on the side, and the joint is made as previously described. Jump welds, Fig. 120, are also made by scarfing the pieces in the same way and welding. Rings, Fig. 121, are made by scarfing the ends of the strip and welding. To determine the length of a piece for making a ring, add the thickness of the stock to the inside diameter of the ring and multiply by $3\frac{1}{7}$. For straight pieces to be welded, add the thickness, or diameter, to the length to allow for the joint.

Butt welds are used, when joining heavy pieces—especially pieces of irregular shape that are to be upset first—and for lengthening pieces of large cross section, such as shafting. Lap

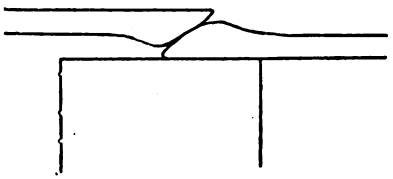


Fig. 115. Scarf Weld

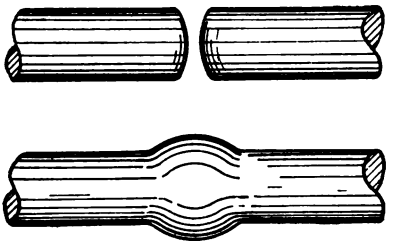


Fig. 116. Butt Weld

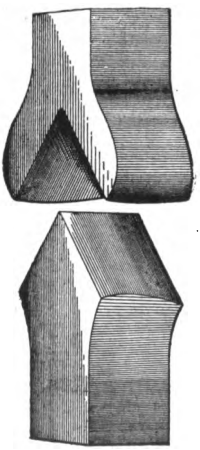


Fig. 118. Cleft Weld

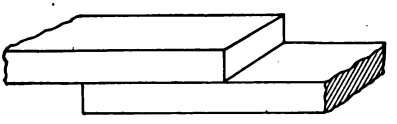


Fig. 117. Lap Weld

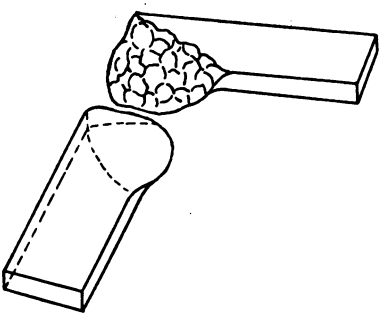


Fig. 119. Corner Weld

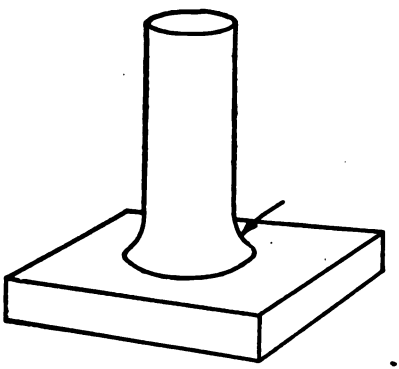


Fig. 120. Jump Weld

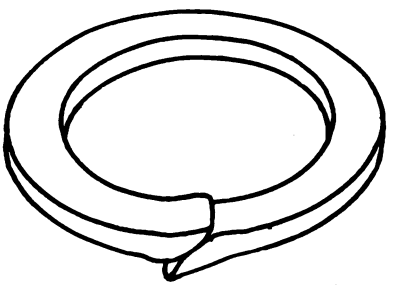


Fig. 121. Ring Weld

welds are used for comparatively thin sections like steel tires, hoops, and plates, and sometimes for making tanks and large piping. Tubes are sometimes lengthened by swaging one part large enough to slip over the other and then lap-welding them by hammering with a mandrel inside to prevent distortion, and to give something to act as the anvil to hammer against. Cleft welds are used when welding steel to iron, as, for instance, putting hard tips on picks, attaching tool steel drills to soft shanks, etc., and for work requiring great strength of joint, such as tie-rods for bridges. Borax should not be used as a flux for this purpose, unless it has first been calcined or melted in a ladle, cooled, and powdered, in order to remove all moisture from it. When making a weld between iron and steel, it is best to heat them both at once; dip the iron in sand and the steel in borax; reheat the iron white and the steel cherry red; and then weld with a heavy hammer. After they are joined, they should be reheated and then finished with a lighter hammer. Steel facing is another welding operation and consists in welding a piece of steel flatwise against the iron to give it a hard surface; it is used in making some kinds of tools.

SOLDERING AND BRAZING

Both the soldering and brazing processes are similar to welding in so far as they are methods of uniting metals, but they are different in that the filling or joining material is usually of different composition from the pieces joined. The work of brazing brass and soldering lead resembles the welding process without the hammering but it is not welding in the proper sense of the term; it is, rather, a sort of "metallic gluing" process.

SOLDERING

Soldering is the process of joining pieces of metal by filling the space between them with material known as "solder," and doing it in such a way that the solder will adhere to both of them and hold them together. The first requirement of a good solder is that it will "wet" the surfaces, or amalgamate with the pieces to be joined. Alloys of lead and tin, with the addition at times of other metals, are the usual solders, although special solders are made without either of them. Soldered joints are not so strong as

welded or brazed joints because of the material used but they are frequently used because they are easily and cheaply made.

The process requires less heat than welding or brazing and the joints may be cooled rapidly. An ordinary gas flame with a

Fig. 122. Soldering Copper
Courtesy of Central Electric Company

foot pump for the blast, or even a candle and a blowpipe, may be used for soldering. If the piece worked upon is so large that it rapidly conducts away the heat, a gasoline or kerosene torch is used to preheat the piece and prevent chilling the solder. The blowpipe is used for small work like jewelry and the only point to watch is to be sure the flame is hot enough to burn all of its carbon. The blue center of a flame is highly oxidizing whereas the yellow outside portion causes a reducing action.

Fluxes. Fluxes are essential to successful soldering and there are several kinds on the market, although most operators soon learn to make their own. The fluxing materials generally used are salammoniac, zinc-chloride solution, rosin in alcohol, borax, and tallow. Flux is used to dissolve grease and to remove any oxide present after cleaning. It combines chemically with the oxide and leaves a clean surface of metal which the solder will wet. Sometimes the flux is combined with the solder when making up the sticks, and this is known as "self-fluxing" solder.

Fig. 123. Soldering Iron Heating Stove
Courtesy of Central Electric Company

Tools. The tools required for soldering are very simple and few in number. The source of heat for the operation is usually a soldering "copper" or "bit," Fig. 122, which has in turn been heated in a gas or charcoal stove, Figs. 123 to 125. It is made with a comparatively large head, small shaft, and wooden handle and has a pointed tip on the head for working. The tip should be

"tinned" before using, and this is done by first cleaning and sandpapering, fluxing with zinc chloride, and heating. While hot it is rubbed well with a stick of tin which adheres to the surface, and it will remain tinned for a long time unless heated to a red heat. A type of grooved soldering copper is shown in Fig. 126, and an electric soldering tool is shown in Fig. 127.

Solders. Most solders melt at about 200 degrees centigrade (392° F.), the softer solders melting at about 180 degrees centigrade (356° F.), and harder solders at about 330 degrees centigrade (626° F.). There are so many special solders on the market that no closer figures can be given, but these will be a safe guide for

Fig. 124. Charcoal Stove
Courtesy of M. Klein and Son

Fig. 125. Gasoline Furnace
Courtesy of Central Electric Company

most of the ordinary kinds of work. Ordinary solder is half tin and half lead. Hard solder is two parts lead and one part tin. Antimony is sometimes added to harden and stiffen solder, and arsenic is added to make it flow more freely. Bismuth makes the solder brittle and cadmium makes it soft. When bismuth and cadmium are both added they reduce the melting point, and "Wood's metal," which contains two parts of tin, two of lead, two of cadmium, and eight of bismuth, melts at 70 degrees centigrade (158° F.). Copper strengthens solder but raises the melting point very rapidly.

Soldering Process. The process of soldering consists in scraping the surfaces clean, heating the pieces to the soldering

temperature by any suitable means, fluxing the surfaces to be joined, applying the solder with the solder bit, and finishing the joint by smoothing off. Rust and grease must be scraped or

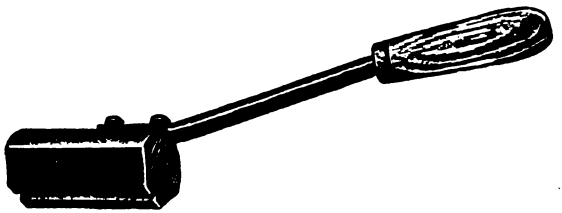


Fig. 126. Grooved Soldering Copper
Courtesy of Central Electric Company

washed off with some alkaline solution. With liquid fluxes it is best to apply them after heating the surfaces to be joined, in order to eat away the film of oxide and keep the surface clean, but with borax or rosin solutions it is best to apply them cold. After the surfaces are properly cleaned, heated, and fluxed, the solder is melted on with a flame or by rubbing with a hot bit; the joint is then smoothed up.

The most important points to watch are the temperature and the flux. Too much heat causes oxidation, makes the solder run too freely, and burns the tinning off the soldering tips. Poor fluxing prevents the solder from amalgamating with the pieces and, hence, they will not join. Platinum, silver, gold, tinned sheet iron, and most other metals may be soldered, but it has thus far been practically impossible to solder aluminum commercially. A

Fig. 127. Electric Soldering Tool
Courtesy of Central Electric Company

number of processes have been devised for soldering aluminum, but none of them are in very general use, and most of them have been failures.

BRAZING

Brazing is a process similar to soldering, the main difference being in the use of a harder filling material and one requiring a higher melting temperature. Gold, silver, copper, brass, and iron

may be brazed and the process consists broadly in melting a filling material called "spelter" into the joint to be made. The spelter used for brazing varies with the nature of the work, the hard alloys consisting of copper and zinc, and the soft ones consisting of tin and copper, or tin and antimony. Hard spelter gives a stronger joint than soft spelter, of course, but in all cases the spelter must amalgamate with the metal joined in order to make a good joint.

Fig. 128. Double-Jet Brazer
Courtesy of Turner Brass Works

Flux. The flux for brazing is made of borax or boric acid, the latter being cheaper. Borax will swell up under the flame, blister, and run off unless the water of crystallization has been burned out, whereas good borax will melt and run over the surface and clean it nicely. The surfaces should be cleaned carefully before brazing, the same as when soldering. Salammoniac, zinc chloride, salt, and various acids have been tried as brazing fluxes, but no other is so good as borax from which all water has been removed.

Equipment. The equipment required for brazing consists principally in having suitable means for heating the pieces to the proper temperature and a supply of the proper spelter. Beyond this there are many good things which assist in making brazing easier, such as special fixtures for holding the pieces while working, torches or furnaces of various sizes, and similar things which will suggest themselves to the worker from time to time. As stated, the things which are necessary are but few in number.

A torch is used when brazing small and moderate-sized pieces and a forge or furnace such as shown in Fig. 128, for heating large pieces. Gasoline or kerosene give more heat than gas, but a blacksmith's forge provides the best means for heating and cooling. The pieces to be brazed should be preheated, brazed, and cooled slowly, and care must be taken to see that any sulphur in the coal or any soot from the fire is kept away from the pieces

to be welded. The parts should not touch the fuel. A reducing or nonoxidizing flame is required and the brazing is done at a high temperature. Iron and steel require almost a white heat and a Bunsen flame with a blue cone is generally used.

Process of Brazing. The process of brazing varies according to the work to be done and is a somewhat more expensive and complex process than soldering. The surfaces to be brazed must be cleaned, of course, by scraping and washing, and then brushing with a wire brush. The borax or other flux is then applied and the pieces placed together ready for brazing. The tighter the parts are clamped, the stronger will be the joint. If no regular furnace is available, a rough one should be built of bricks, Fig. 129,

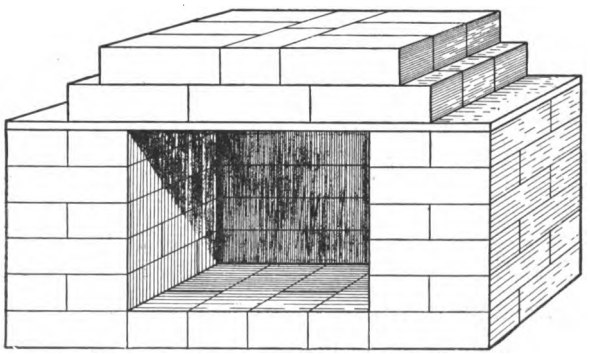


Fig. 129. Temporary Brick Furnace for Brazing

so as to enclose the articles on all sides but one, in order to retain the heat.

There is considerable variation in the practice of brazing, for the details of the operation depend upon the nature of the work to be done, the size and the shape of the pieces, the material, etc. For the production of pieces in quantities, especially articles made of sheet metal, the spelter is melted in a ladle or pot and the pieces are dipped therein. In this operation the flux is floated on top of the spelter and the pieces are cleaned before dipping. The flux then does its work as the articles are dipped into the spelter.

For castings and other articles which require brazing but which cannot be dipped because of the nature or location of the joint, it is customary to prepare the joint as previously described.

Place the pieces together in proper position; build a temporary furnace around the piece, or place it in a suitable furnace; and then heat it by playing a flame on it. Gas torches with air blast, Fig. 130, make good heaters and the temperature may be regulated to suit the size of the piece. When the article is properly heated and fluxed, the spelter will flow into the space between the parts, wet both surfaces fully, and make a tight joint.

Care should be taken to see that the article does not cool too quickly, especially iron castings, or unequal shrinkage will cause cracking. Heating should also be gradual to prevent unequal expansion for the same reason and burning must be avoided. Sometimes the pieces may be covered with graphite paint, except where the brazing is to be done, thus preventing the flame from affecting those parts. This is especially important when brazing brass as it should prevent the zinc from volatilizing and passing out of the alloy, thus leaving it spongy. The brazing of gold and silver requires special alloys; this is usually put in the hands of a jeweler and, as it is generally a small job, it is usually done with a blowpipe.

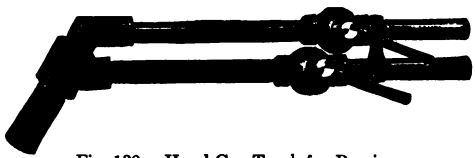


Fig. 130. Hand Gas Torch for Brazing
Courtesy of Turner Brass Works

Use of Brazed Joints. Brazed joints are often stronger than the original metal, but are not so good as welded joints, although they are cheaper and easier to make. Cast-iron pieces will not break at the joint when properly brazed, and such joints are about 15 per cent stronger than the casting. One of the greatest objections lies in the possibility of leaving flux or rust in a brazed joint and weakening it. There is also danger of electrolytic action between the spelter and the material brazed and brazed joints do not always stand up well under repeated shocks. On the other hand, on articles of steel there are probably more joints made by brazing than by any other process except riveting, thus proving it to be a generally reliable commercial process.

RIVETING

Riveting is not a welding process but it deserves a place in any treatise on the art of joining metals because it is in such

general use for that purpose. While it is true that riveting is rapidly being superseded in many cases by various welding processes, it will never be abandoned entirely, and it is therefore worthy of consideration here.

Details of Process. The process of riveting consists in joining pieces of metal by means of rivets, which are short pieces of soft bars or rods with a head on one end. They are usually made of the same material as the pieces to be joined, such as steel, iron, copper, brass, aluminum, etc., and are used hot or cold as may be required. Steel and iron rivets for joining plates or other pieces of the same materials are usually red-hot when used; so they are easier to head over and will draw the pieces tightly together as they shrink while cooling. Rivets of softer materials are used cold.

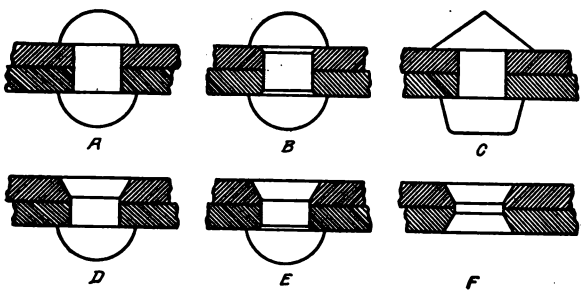


Fig. 131. Types of Rivet Heads

Shapes of Rivet Heads. The more common forms of rivet heads are shown in Fig. 131, wherein *A* shows a plain round head on both sides of the plates; *B* shows a round head on both ends, but with the plates slightly countersunk to form a shoulder under the head for added strength; *C* shows a plain rivet with a pointed or steeple head above and a rose, or cone, head below; *D* shows a countersunk head above and a round head below; *E* is similar to *D* with the lower plate countersunk to give a shoulder under the head, and *F* has countersunk heads both above and below. Round heads are most commonly used; steeple and cone heads are used for boilers; and countersunk heads are used only when necessary for finish or to avoid some other attachment.

Tank and Boiler Work. When making tanks, pipes, boilers, or other articles of steel plates, the first operation is to shear the

plates to the desired size and then trim the edges. Rivet holes are then punched or drilled near the edges of the plates, these being of the proper size and quantity for the strength demanded.

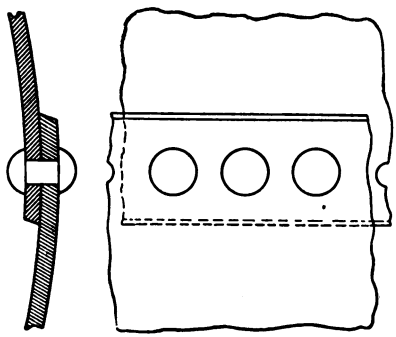


Fig. 132. Single-Riveted Lap Joint

If the article to be made is cylindrical in form—such as a boiler—the plates must be bent to the proper shape by being passed through rolls after the rivet holes are made. A few bolts should be put into some of the holes, after the plates have been placed in proper position for riveting, in order to hold the plates in place until the rivets have been driven and set. These can then be removed and rivets substituted for them. Rivets always used to be headed over by hand but machine riveting has been adopted now for nearly all work done in shops and a large part of that done in the field; it is much to be preferred on account of its uniformity.

Types of Joints. The joints used in riveting plates are either of the butt or lap type; in the former the pieces are brought together edge to edge, and in the latter they are overlapped. The added plate is known variously as a "welt strip," "cover plate," or "butt strap"; two of them are used for extra heavy work. Where the plates lap over and a single row of rivets is used, the joint is known as a "single-riveted lap joint," Fig. 132, this being the commonest and most used form of joint and being entirely suitable for the majority of seams. Where the plates lap further and two rows of rivets are used, as in Fig. 133, it is called a "double-riveted lap joint," this type being used for moderately heavy plates or for high pressures. If the plates are brought together edge to edge and a cover plate

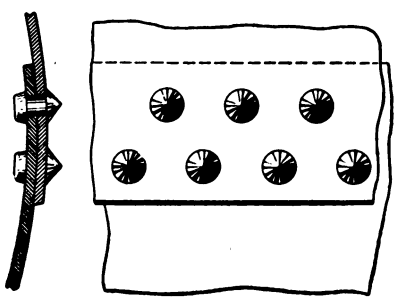


Fig. 133. Double-Riveted Lap Joint

put on one side as in Fig. 134, it is known as a "butt joint with a single strap." Such a joint is frequently used for the lengthwise seams of tanks or boilers. For very high pressures and heavy plates the custom is to use a "butt joint with two welt strips," two rows or three rows of rivets being used through both plates and strips, and an additional row passing through the inner strip and plates only, Fig. 135. Other types of joints are sometimes used but these are the most common and most easily made. When a single butt strap is used, it is about $1\frac{1}{8}$ times the thickness of the plates but when two are used, the outer one is of the same thickness as the plate and the inner one is about $\frac{3}{4}$ the thickness of the plate. Butt joints should be used for plates over $\frac{1}{2}$ inch thick, two strips being used. Wherever longitudinal and girth seams meet, the plates should "break joints," as shown in Fig. 136, rather than be continuous. The inside lap is made to face downward so as not to form a ledge for the collection of sediment, Fig. 137.

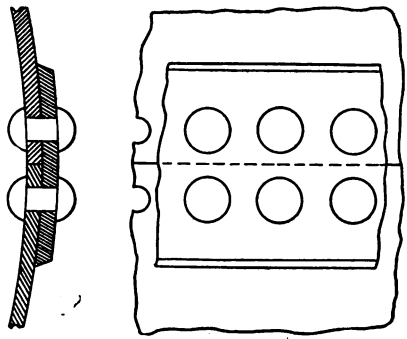


Fig. 134. Butt Joint with Single Strap

Strength of Joints. The strength of a riveted joint depends upon the materials used, the diameter and numbers of rivets, and the way in which the strain is applied to the rivets. The plate may break along the line of the rivet holes; the rivet itself may shear off; the plate may shear out in front of the rivet or it may simply crush in front of the rivet. Rivets should never be used where they are subjected to a tensile or pulling strain as their greatest strength is when in shear or crosswise strain. If they can be placed in double shear through using butt joints

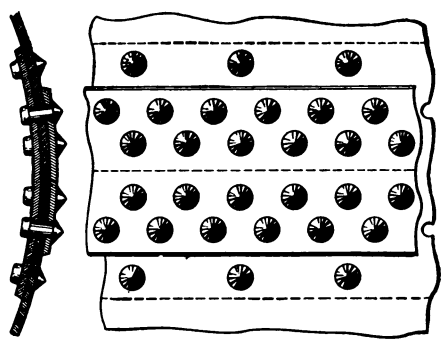


Fig. 135. Butt Joint with Two Welt Strips

and butt straps on both sides, they work still better. Plates seldom shear in front of the rivets, but sometimes they break along the

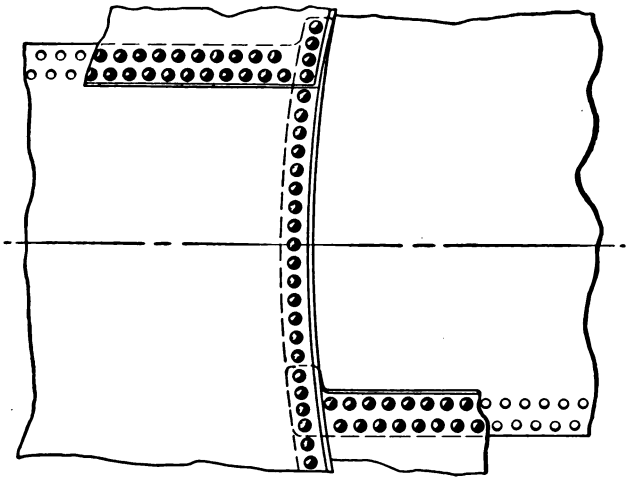


Fig. 136. Typical Boiler Shell Showing Method of Riveting and Breaking Joints

line of the rivets and rivets sometimes shear off or pull out under heavy strains.

Table XVI gives the figures used by several boiler and tank makers for riveted joints and applies to single-strap butt joints and lap joints. By "efficiency of joint" is meant the relative strength of the joint and the rest of the plate; by "pitch" is meant the distance between the centers of the rivet holes in the plate.

When laying out plates and riveting, care should be taken to see that the various longitudinal seams do not come in line with each other, but that they are offset, or "staggered." The inner

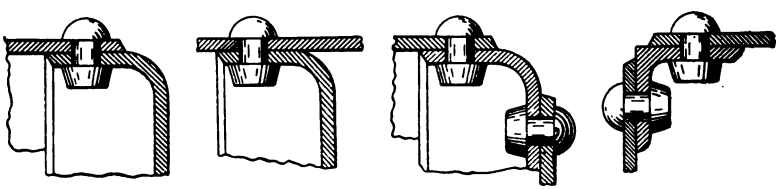


Fig. 137. Methods of Making Riveted Seams in Tanks

plate of the longitudinal seam should be hammered thin at the edge where it comes to the circumferential or girth seam so that

TABLE XVI

Efficiency of Single-Strap Butt Joints and Lap Joints

Thickness of Plate, Inches	Diameter of Rivet, Inches	Diameter of Hole, Inches	Pitch		Efficiency of Joint	
			Single, Inches	Double, Inches	Single	Double
$\frac{1}{4}$	$\frac{5}{8}$	$\frac{11}{16}$	2	3	.66	.77
$\frac{5}{16}$	$\frac{11}{16}$	$\frac{3}{4}$	$2\frac{1}{16}$	$3\frac{1}{8}$	.64	.76
$\frac{3}{8}$	$\frac{3}{4}$	$\frac{13}{16}$	$2\frac{1}{8}$	$3\frac{1}{4}$	.62	.75
$\frac{7}{16}$	$\frac{13}{16}$	$\frac{7}{8}$	$2\frac{3}{16}$	$3\frac{3}{8}$	.60	.74
$\frac{1}{2}$	$\frac{7}{8}$	$\frac{15}{16}$	$2\frac{1}{4}$	$3\frac{1}{2}$	.58	.73

the rivets can draw the plates tightly together at all points; otherwise there will be leakage.

When rolling iron and steel plates, there is a fiber formed lengthwise of the plates in the direction they are rolled and, when making boilers or tanks, it is important that this fiber should run around the boiler in the direction of the girth seams to get the greatest strength. When ordering plates, it is customary to give that dimension first which indicates the way the fiber must run. When plates are to be flanged or turned up around the edge, as for heads of tanks or boilers, the curve at the corner should have a radius equal to at least four times the thickness of the plate, and the material should be of the best quality.

Calking. Calking is the operation of closing the edges of a riveted joint to make the plates fit tight and give a good joint. A round-edged tool, Fig. 138, is driven against the edge of the overlapping plate so as to make it flow down against the other plate and close up any space between them at the edge. Unless this operation is properly done, however, the seam may be opened instead of closed and the joint be made worse than before, and this is one of the operations that is being superseded by electric welding. Electrical calking is done by using a metallic electrode and depositing metal along the edges of the plates by means of the heat from an arc, thus covering the joint and drawing the two plates together.

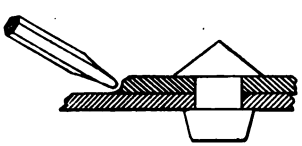


Fig. 138. Calking a Riveted Seam

Riveting Tools. The tools required for riveting consist of hammers, calking tools, rivet sets for forming the heads, rivet heat-

ing furnaces, punches, shears, drills, drifts for drawing the holes in line, and, in some cases, pneumatic or hydraulic riveting machines. For the average small shop it will be sufficient to have hammers, heaters, shears, punches, and drifts, with a set or two for the heads. The use of drift pins for drawing the holes in line is very common practice on cheap work, but should never be done on a good job, as it distorts the holes and prevents the rivets from filling them. Punched holes should not be used for good work as this operation is likely to injure the plates. Drilling is preferable, especially for steel plates.

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